A STUDY OF MECHANICAL PROPERTIES AND CRUSHING PERFORMANCE OF CARBON FIBER WOUND TO HDPE PIPE (CFWHP)

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15986

Dissertation submitted in partial fulfilment of the requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

FYP II JANUARY 2015

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CERTIFICATION OF APPROVAL

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Approved by,

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(AP IR DR HAMDAN HAJI YA)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JAN 2016

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the

original work is my own except as specified in the references and acknowledgements,

and that the original work contained herein have not been undertaken or done by

unspecified sources or people.

(BHUVANA RUEBEN A/L AIYYAPPAN)

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ABSTRACT

Carbon fiber-reinforced polymer, is a type of composite polymer which is highly regarded as one of the best alternatives for light weight, strong and anti-corrosion material. Composite polymer consists of 2 main constituent materials which are matrix and reinforcement which are fabricated using the filament winding technique. This material is vastly used in various industries such as the automotive industry, oil and gas industry, aerospace industries and also industries that demands a high strength-to- weight ratio criteria. The focal point of this research is to study the effect of different carbon fiber tow arrangements on the carbon fiber tow wind to HDPE composite pipe (CFWHP) and their mechanical properties. There are 3 types of samples used in this project, both with different carbon fiber tow arrangements. These samples will be then fabricated in SIRIM Permatang Pauh using epoxy resin as the desired matrix to form the composite material. The first sample with an arrangement of 4 fiber tows of 12k carbon fiber (total of 48k) with a winding angle of 57°. Followed by the second arrangement of 2 fiber tows of 12k carbon fiber and 4 fiber tows of 6k carbon fiber (total of 48k). Lastly, the third and final arrangement of 8 fiber tows of 6k carbon fiber (total of 48k). Consequently, tensile test and compression test will be done to get an idea on how the mechanical properties of CFWHP will be affected by the different carbon fiber tow arrangements.

ACKNOWLEDGEMENT

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CHAPTER 1

INTRODUCTION

1.1 Background

The world has now become a platform that is in need for engineering work that will coincide with the huge demands of leading industries such as the automotive industry and also the oil and gas industry due to the increasing human population. With that said, the plea for more high performance materials such as the carbon fiber reinforced polymers (CFRP) are increasing as we speak. This project is primarily aimed at the oil and gas industry since the existing steel pipelines are only able to provide limited benefits and are also subjects to corrosion. Due to this fact, the industry is now shifting their attention towards nonmetallic pipelines. According to the Saudi Aramco News, nonmetallic pipes are designed to last for 25 years in the field, which is a significant improvement in piping lifespan compared to the conventional metallic pipes [1].

CFRP is a type of composite material where it is made out from carbon fiber and also epoxy resin. Due to the usage of carbon fiber, the manufacturing cost of CFRP falls more on the higher side. Despite the high cost, CFRP are also broadly used in the aerospace industry for the manufacturing of ailerons, gear doors and engine nacelles. Besides that, CFRP are extensively used in the making of exotic cars where high strength-to-weight ratio is needed to manufacture the high performance vehicles. Moreover, CFRP are now slowly making their climb up the oil and gas industry as it has the capability to withstand the harsh subsea environment. All in all, the performance and the durability provided by the CFRP clearly makes up for the high manufacturing cost on the long run. However, there are also ways to also reduce the cost competitiveness with new technological manufacturing techniques.

In order to reduce the manufacturing cost of the CFRP, a technique called filament winding is used to wind the carbon fiber onto the high density polyethylene pipe (HDPE). This technique has been identified as the most efficient and least costly way to manufacture composite materials [2]. The primary interest of this project lies in the relationship between various sizes of carbon fiber tow arrangements being wind onto the HDPE pipe and how it affects the mechanical properties. However, the mechanical properties of the carbon fiber wind to HDPE pipe (CFWHP) are highly dependent on the proportions of carbon fiber and epoxy resin, orientation of carbon fiber, types of epoxy resin, and size of carbon fiber and length of carbon fiber for discontinuous carbon fiber and void content [3].

Throughout this project, the winding angle, winding tension, resin content, and winding layer will be kept constant. The only manipulated variable in the project will be the usage of various sizes of carbon fiber tow arrangements. Theoretically, by utilizing similar sizes of fiber tow, small triangles or voids will be formed at every crossing part which will then affect the properties of the CFWHP. In order to enhance the mechanical properties of the CFWHP, the voids could be reduced by introducing the different sizes of fiber tow arrangement but maintaining the same number of filaments in the sample. Several tests such as tensile test and compression test will be done to study on how the different types of carbon fiber tow arrangements affects the mechanical properties of the CFWHP. At the end of the research, the results will be then tabulated to conclude on the main objectives of this study.

1.2 Problem Statement

In the oil and gas field, it is roughly estimated that around 1.4 billion US dollars is expended annually due to corrosion in the pipelines that are made out from metallic pipelines. At the event of any leaking, 50% of the time, it is caused by corrosion [4]. How do we avoid this from occurring? For this research, the primary point lies in the arrangement of the carbon fiber tow. There are 2 types of fiber tow bundles that will be used. One being the 6k fiber tow, followed by the 12k fiber tow. These 2 samples are the ones that are most commonly used in the market. The reason why we manipulate the carbon fiber tow arrangements is to investigate on the formation of voids.

Voids will be formed due to small gaps at every crossing part when the fiber is being wound around the mandrel [5]. These voids will then affect the mechanical properties of the carbon fiber wind to HDPE pipe (CFWHP). So in order for us to find out the impact that these voids have on the mechanical properties, a few tests must be done, such as the compression test and tensile test. This will then prove crucial for us to understand on which type of carbon fiber tow arrangement gives out the best mechanical properties.

1.3 Objective

The objectives of this project:

i. To study how various sizes of carbon fiber tow arrangements affect the level of enhancement of mechanical properties the carbon fiber wind to HDPE pipe (CFWHP)
ii. To analyze and discuss the findings obtained from the microstructure test, tensile test and compression test respectively.

1.4 Scope of study

The scope of study of this project:

i. Conclude and study the results obtained from the tensile test, and compression test on the carbon fiber wind to HDPE pipe (CFWHP)
ii. Take on the issue of the formation of voids in the CFWHP in order to enhance its mechanical properties

1.5 Relevancy And Feasibility Of Project

The project is seen as important as it is looking into new possibilities of funding alternative measures for pipelines in the oil and gas industry. The reason behind this project is because of the high tendency of the commercial steel pipeline being subject to corrosion. With the usage of carbon fiber reinforced polymer (CFRP), corrosion in pipelines can be neglected as this composure material is corrosion resistant. Although it is expensive, it will help oil companies save money in the long run by reducing maintenance and downtime due to corrosion. Consequently, this project is very much relevant as the subject matter is not widely studied into maximum potential. The project is feasible since it is dealing with a specified scope of experiment. In this experiment, the effect of different carbon fiber tow arrangements on the mechanical properties of carbon fiber wound to HDPE pipe (CFWHP) will be studied. It is within capability of the student to conduct the study with the guidance from the supervisor. It is positive that this project can be conducted and accomplished with the given period.

CHAPTER 2

LITERATURE REVIEW

2.1 Composite Material

A composite material is created by bringing together two or more materials of different properties. The combination of these various properties usually produces an end product that is higher in quality and possess distinctive properties. Composite materials come into play most of the time in our lives. For example, it is used in the making of sporting equipment, body armor, aircraft parts and water pipes. The materials that make up the composite material are called constituent materials [6]. There are two primary types of constituent materials involved, mainly the reinforcement and matrix. Both of these materials play their own pivotal roles in creating a proper composite material. The reinforcement in this case acts as the material that gives the end product its mechanical and physical properties. On the other hand, the matrix plays a supportive role that maintains the positions of the reinforcement material or particles in place [7]. When compared to the commercial materials, composite materials tend to have the upper hand in many aspects. One of them is that composite materials that it is lightweight and easy to transport. This property will then contribute accordingly, depending on which field that the composite material is being subject to. Looking at the automotive industry, lightweight equates to more fuel savings. Then, in the energy industry, fan blades which weigh lesser possess the ability to produce more energy as it requires less force for the wind to rotate the blades. Hence, more power is being produced by the turbines [8].

As said earlier the main application of the project is aimed towards the oil and gas industry. Composite materials are now beginning to be the attention grabbers when compared to the more commercialized pipelines that are made out of metal. The advantages provided by the pipelines that are made out from composite materials are in abundance. The crucial one is that the composite materials possess non-corrosive properties. Furthermore, composite materials also require low maintenance and are long lasting [8]. Composite stiffness can be predicted using a micro-mechanics approach termed the rule of mixtures. Where the rule of mixtures' equation is as below in Equation 1:

$$E_C = E_F V_F + E_M V_M = E_F V_F + E_M (1-V_F) \qquad (1)$$

Where: E_C = tensile strength of the composite

E_F = tensile strength of the fiber

E_M = tensile strength of the matrix

V_F= volume fractions of the fiber

V_M= volume fractions of the matrix

2.2 Carbon Fiber as Reinforcement

Carbon fiber is a type of material that comprises of fibers enclosing carbon atoms that are aligned together to form a long axis. Carbon fiber is a super strong material which is also lightweight at the same time. It is widely preferred as it is almost five times the strength of steel. The other properties of carbon fiber include high stiffness, high strength, lightweight, high chemical resistance and high temperature tolerance [9]. Actually, glass fibers are the more common fiber compared to carbon fibers but due to the difference in strength, carbon fibers are highly preferred commercial wise. These properties will prove to be a huge advantage when the application of the carbon fiber is targeted towards the oil and gas industry, which is the main application of this research. In the formation of carbon fiber reinforced polymer (CFRP), the carbon fiber acts as one of the two constituent materials involved in the composite material formation process. The two constituent materials being the reinforcement and matrix materials.

In this case, the carbon fiber acts as the reinforcement material. The role of the reinforcement material is to display the mechanical and physical properties of the desired composite material. With that said, the reinforcement material frequently possess high tensile and compressive strengths. However, these cannot be achieved in the structural form as there might be impurities present or other flaws during the processing period. This flaws will then subsequently lead to formation of cracks. Hence, the strength of the composite material will be affected [10]. However, when combined with a matrix material of higher density, the reinforcement also aids to reduce the density of the composite material, thus enhancing the mechanical properties of the composite material such as specific strength [11].

2.3 Epoxy Resin as Matrix

In today's modern day manufacturing field, there are a total of three types of resins used to bind carbon fibers together onto polymers. They are epoxy resin, vinyl ester and polyester resins respectively. The reason why that epoxy has been chosen as the desired resin is because it is the strongest among the three resin types. To be precise, it is roughly three times stronger than vinyl ester and polyester resins. Epoxy resins are vastly used in the aerospace industry, automotive industry and also the marine industry. They are mainly used as adhesives and also structural matrix [12]. However, among all the resin types, epoxy resin is the most expensive but it is worth every penny. Besides that, when combined with carbon fiber to form a composite material, the epoxy resin stands out and it also form a practically leak-proof barrier [13]. One of the setbacks is that the curing time for the epoxy is lengthier compared to vinyl ester and polyester resins. Curing occurs at any temperature from 5°C to 150°C, however, their prolonged range of properties can make epoxy resin the performance choice for critical applications [14]. These are the reasons why the epoxy resin has been designated as the desired resin in this project.

The matrix plays a crucial role in the forming of any composite material. The main function of the matrix is to bind and support the reinforcement material by making sure the position of the material is always maintained. Usually, the composite materials are categorized based on the matrix material. For instance, it can be either polymer, metallic or even ceramic. Not only that, the matrix does not only serve as a holder for the reinforcement material, but it is also acts as a barrier to protect the reinforcement material from harm either triggered by corrosion or high temperatures. On top of that, the matrix also aids in spreading the load evenly to each individual reinforcement material. As said earlier, there might be certain flaws during the processing period of the reinforcement material which will then lead to the emerging of cracks. Through technological developments, it has been uncovered that this issue can be solved by combining the reinforcement material with a matrix material so that there is more stability involved during the formation of the composite material [5].

2.4 High Density Polyethylene (HDPE)

High density polyethylene (HDPE) is a type of petroleum made thermoplastic. Today HDPE has become one of the most used thermoplastics for production of plastic items, utensils, films and pipes. HDPE is readied from ethylene by a catalytic process. The nonattendance of branching results in an all the more firmly stuffed structure with higher density and to some degree higher chemical resistance compared to Low Density Polyethylene (LDPE). Other than that, HDPE also possess higher specific and tensile strengths. They are also capable of withstanding temperatures ranging up to 120°C [15]. Our project will be focused on to the HDPE pipes that is used in the oil and gas industry to transfer oil at high pressures and speeds. It is known for a fact that the lifespan of the HDPE pipes can be over 50 years which is astonishing contrasted with its predecessor, the carbon steel pipes, which can last up to around 20 years in the field.

The application of HDPE in the oil and gas industry may prove to bring a number of benefits to the users. One of the main benefits is that the HDPE pipes are resistant to corrosion and they do not undergo rusting as well. Furthermore, the pipes are also leak tight or leak proof. The heat fused joints create a far stronger bond compared to the HDPE pipe itself. Other than that, the flow rates are also known to be kept at optimum rates. Since polyethylene is smoother than steel, cast iron, ductile iron, or concrete, HDPE pipe that is smaller in size has the ability to convey an identical volumetric flow rate at the same pressure Other than that, it has less drag and a lower chance for turbulence at high flow. In addition to aid the installation process, HDPE pipes are lightweight and they require light equipment for handling them. This will also come in handy when it comes to the installation costs. HDPE permits bending without the requirement for an excessive number of fittings. Since HDPE is not a fragile material, it can be introduced with bends around uneven territory effortlessly in constant lengths without extra welds [16].

2.5 Filament Winding Technique

Filament winding technique is a type of process that is focused on the manufacturing of open or closed end parts. The working procedure includes winding fibers over a mandrel under tension, in the case of the project, the mandrel would be the HDPE pipe. The mandrel rotates while a wind eye on a carriage moves on a level plane, putting down fibers as indicated by the designated pattern. The most common fibers used would be glass fibers and carbon fibers. Carbon fibers would be the chosen fibers in this project and would be coated with epoxy resin as they are wounded onto the HDPE pipe. Once the mandrel has been secured totally as per the thickness wished, the mandrel is put in an oven to cure and solidify the resin. The mandrel is then taken out, hence delivering the hollow end component.

When the filament winding process is being conducted, there are a few parameters that have to be manipulated, which are the winding tension, winding angle and also resin content in every layer of the reinforcement. This is to guarantee fancied thickness and quality of the composite are accomplished. The properties of the completed composite can be shifted by the sort of winding pattern chosen. Besides that, there are three fundamental fiber winding patterns, they are hoop winding, helical winding and polar winding. However, in this project, helical winding has been chosen as the desired type of winding as it is the most common one used in piping and vessels among the three. There are a few reasons why the filament winding technique has been chosen as the desired technique over others. The main one being that this technique can give an optimal balance between hoop strength, tensile strength and torsion resistance. When combined with a high fiber tension when applying the filaments, it results in a comparatively thin walled product. On top of that, the epoxy resin or carbon fiber proportions are controlled through computers. By this way, human error can be avoided and it will lead to less variation in wall thickness in the end products. On top of that, this technique also provides consistent product quality due to the highly automated nature of the process [17].

It is important to find the optimum winding angle for filament winding. Several efforts have been done to achieve this purpose. Based on previous studies, netting analysis is one of the attempts to optimize composite tubular structures. This technique assumes that fibers supported all loads, neglecting the contribution of the matrix and the interaction between the fibers. The optimum angle obtained from this technique which is **57°** is normally used to manufacture composite tubular structures under close-end loading condition [19]. Optimum winding angle can be estimated by using ultimate tensile strength along with applying netting analysis respect to 2:1 hoop-to-axial stress ratio as it is shown at Equations (2) and (3), as illustrated in the figure below. The body diagram of the cylinder consists of axial and hoop forces wrapped with the fibers at the angle of "α" is indicated in the Figure 2.1 [20].

$$N_\theta = \sigma_u t \, sin^2\alpha \quad , \quad N_\emptyset = \sigma_u t \, cos^2\alpha \tag{2}$$

$$\frac{N_\theta}{N_\emptyset} = tan^2\alpha = 2 \;\rightarrow\; \alpha = arc\tan\left(\sqrt{2}\right) = \mathbf{57°} \tag{3}$$

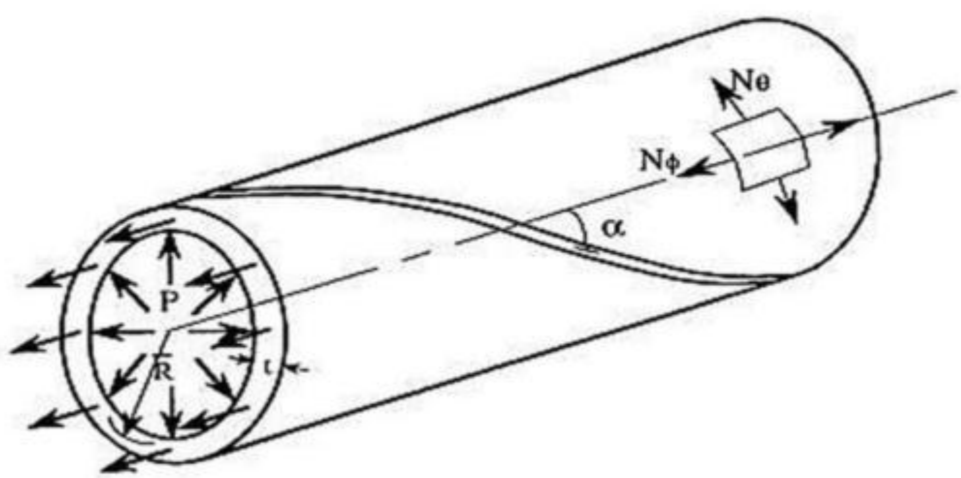

FIGURE 2.1: Body Diagram of Axial and Hoop Forces and Internal Pressure

2.6 Tensile Test

Tensile testing is utilized to measure the force needed to break a polymer composite sample and the degree to which the sample stretches out or extends as far as possible. The data is routinely used to demonstrate a material, to diagram parts to withstand application power and as a quality control check of materials. Since the physical properties of various materials can contrast dependent upon surrounding temperature, it arrives and there suitable to test materials at temperatures that reproduce the normal end use environment [21]. Tensile tests will be performed to measure the tensile properties like tensile strength, tensile modulus and elongation at break. The tensile tests will be measured by using a universal testing machine model AI-7000 M (Figure 2.2) according to ASTM D638.

FIGURE 2.2: AI-7000 M Universal Testing Machine [21]

The mechanical property for tensile is tensile modulus. Solid body distorts when a heap is connected to it. In case of when the material is elastic, the body returns to its unique shape after the heap is removed. The material is straight if the proportion of burden to deformation stays steady in the midst of the loading process. Very few materials are straight and flexible past a little measure of deformation. A steady Young's modulus applies to just straight flexible materials. A perfect inflexible material has an endless Young's modulus in light of the fact that an interminable power is expected to distort such a material. A material whose Young's modulus is high can be approximated as unbending [21].

Tensile tests create a stress strain graph, which is utilized to decide tensile modulus. ASTM D638 testing covers the determination of the in-plane tensile properties of polymer matrix composite materials reinforced by high-modulus strands. The composite material structures are limited to continuous fiber or discontinuous fiber-reinforced composites in which the laminate is balanced and symmetric as for the test course. This test decides in-plane tensile properties of polymer network composite (PMC) materials reinforced by high-modulus strands. Composite material structures are restricted to continuous fiber or discontinuous fiber reinforced composites where the laminate is adjusted and symmetric concerning the test direction. A tensile sample is mounted in the grasps of the testing machine. More often than not, load deformation or load strain curves are plotted or digitally accumulated amid the test for the determination of the elastic modulus [22].

2.7 Compression Test

Technically, compression test is an extremely useful way for large strain hardening response of metals. Besides that, it is also convenient to prepare the specimens to undergo testing. A length of pipe is placed in compression test machine and is subjected to an increasing compressive load until failure occurs. The length change of the specimen and the corresponding load is recorded at set intervals during the test. Strain gauges may be attached to the test specimen to measure dimensional changes in the axial directions. Compressive stress and strain are calculated and plotted as a stress-strain diagram which will then be used when finding the elastic limit, proportional limit, yield point, yield strength and compressive strength.

FIGURE 2.3: Universal Tensile Machine for Compression Test

According to the research of “A study on crushing behaviors of composite circular tubes with different reinforcing fibers” by Jung-Seok Kim, Hyuk-Jin Yoon, Kwang-Bok Shin [23], seven different kinds of circular tubes distinctly UD carbon/epoxy, UD Kevlar/epoxy, UD carbon-Kevlar/epoxy, UD Kevlar-carbon/epoxy, PW carbon/epoxy, PW Kevlar/epoxy and PW carbon-Kevlar/epoxy were fabricated. Compression tests were carried out using a 100kN capacity hydraulic loading machine. All tubes were compressed until the load increased fast by piling of debris inside them at loading rate of 10mm/min. During the tests, the load-displacement data was recorded as a function of time at intervals of 0.1s. Five replicated tests were carried out [23].

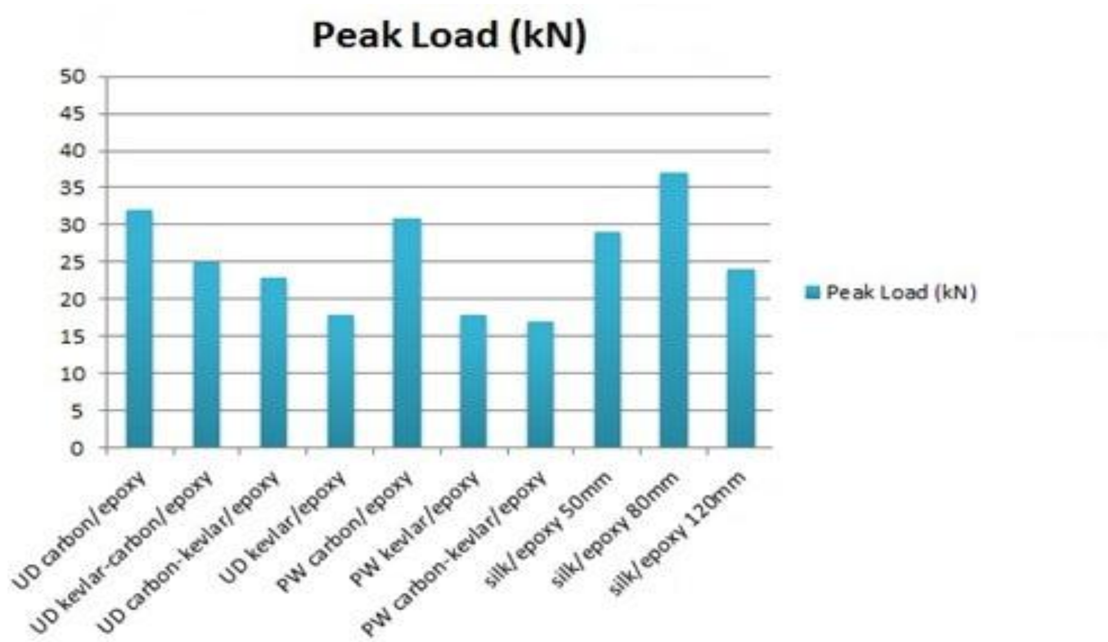

FIGURE 2.4: Peak Loads of Past Research Samples

2.8 Microstructure Test

Scanning Electron Microscope (SEM) is used to examine microstructure of the carbon fiber reinforced polymers (CFRP) samples and the formation of voids using different arrangement of fiber tow (fiber tow of same size and different size). The examination of the microstructure is done using a SEM model Phenom World Pro X that produces images of a sample by scanning it with a focused beam of electrons. SEM can give information about the sample’s surface topography and composition.

FIGURE 2.5: Scanning Electron Microscope (SEM)

2.9 CRFP in Oil & Gas Application

Carbon-fiber-reinforced polymer (CFRP) has become a prominent choice in applications. The advantages of CFRP over steel as a pre-stressing material are namely lightweight and corrosion resistance. These characteristics should enable the material to be used for offshore environments. A research on Reinforced Composite Piping Technology found that fiber-reinforced polymer are better than steel in terms of the weight, to have the ability to withstand high internal pressures, good corrosion resistance, impact resistance and torsion stiffness, lower life cycle cost, have smooth surface and better dimensional stability over temperature fluctuations [24]. It is proved that FRPs are better in terms of corrosion resistance as compared to steel where an experience from an oil company's used FRP pipes in low pressure water injection networks at offshore installations outside the coast of Africa finds that there are no signs of corrosion detected with Glass FRP pipes 12 after 2 years whereas the first holes were observed after approximately 6 months with carbon steel [25].

Carbon fiber reinforced composite (CFRP) is also found to be ideally suitable material for deep ocean applications. CFRP specimens when exposed at four depths namely 500, 1200, 3500, 4800 and 5100 m depths for 174 days did not lost in weight from weight loss measurement [26]. Ultimate tensile strength from tensile test result for exposed specimens is compared with controlled specimens. Tensile modulus data showed no significant variation in property compared to control specimens. Compressive strength of exposed specimens was also compared with control specimens. All the facts clearly proved that deep-sea environment cannot affect the fiber/matrix interface. CFRP had not undergone any change in property even after exposure in deepwater with temperature test as high as 150°C. It can be concluded that carbon fiber reinforced composite is a suitable material for deepwater applications through all the observation results obtained.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

In this project, the focal point lies on the behavior the carbon fiber wind to HDPE pipe (CFWHP) gives when different types of carbon fiber tow arrangements are used when forming the CFWHP. This final year project (FYP) has been divided into two major parts, they are FYP I and FYP II. As mentioned earlier, a number of tasks needs to be carried out before the final results of the research can be obtained. Hence, the tasks has been divided accordingly between FYP I and FYP II.

FYP I

- Preliminary research on carbon fiber wind to HDPE pipe (CFWHP)
- Study the effect of different arrangements of carbon fiber tow on the mechanical properties of CFWHP
- Perform microstructure test using SEM machine using different carbon fiber tow arrangements
- Analyze and conclude the results obtained from the microstructure test

FYP II

- Perform tensile test and compression test on CFWHP
- Analyse and discuss the behavior of CFWHP under the conducted tests

3.2 Process Flow Chart

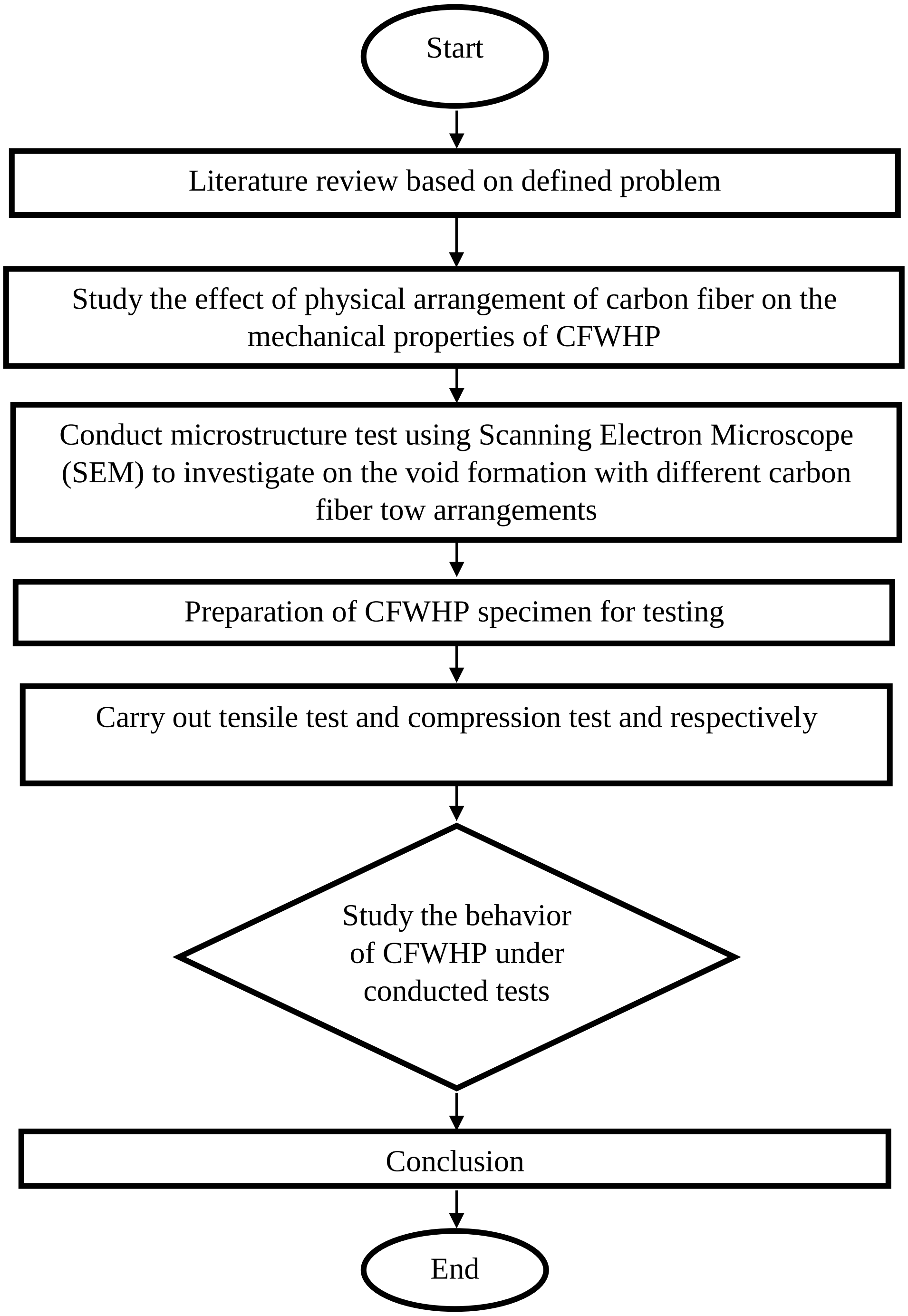

FIGURE 3.1: Project Process Flow Chart

3.3 Fabrication of CFWHP

In this project, 3 samples of carbon fiber wind to HDPE pipe (CFWHP) were fabricated. Both of the samples are having 57° as the winding angle and 6 layers as the winding thickness. 3 HDPE pipes with length of 2 meter each were used for each sample respectively. CFWHP were produced by using 3-spindle, 4-axis filament winding machine in SIRIM Permatang Pauh.

The process of fabricating the carbon fiber reinforces plastics is as below:

1) The mandrel consisting of HDPE pipe (Figure 3.2) is attached to the machine.

FIGURE 3.2: Liner for Winding

2) Four 12k (Sample A) fiber tows of carbon fibers are passed through the resin bath (Figure 3.3) consists of epoxy. As it rotates, the roller comes in contact with the fibers, so that the fibers are coated with the resin.

FIGURE 3.3: Resin Bath

3) The fibers coated with epoxy are wound around the mandrel (Figure 3.4).
4) The fibers move in lateral movement while the mandrel rotates with constant speed. Several lateral movements are made to achieve the 6 layers thickness.

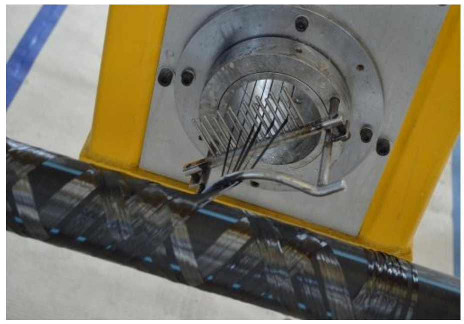

FIGURE 3.4: The Fibers Wounding the Mandrel

5) The fiber tows are cut when the sample finished. The mandrel rotates for a few hours until the sample has hardened.
6) The sample was removed from the mandrel and placed in an oven (60 °C) in duration of 3 hours for curing.
7) Steps 2 to 6 are repeated using two 12k and four 6k (Sample B) fiber tows and eight 6k (Sample C) fiber tows.

3.4 Microstructure Test

SEM is used to examine microstructure of the carbon fiber reinforced polymers (CFRP) samples and the formation of voids using different arrangement of fiber tow (fiber tow of same size and different size). The examination of the microstructure is done using a SEM model Phenom World Pro X that produces images of a sample by scanning it with a focused beam of electrons. SEM can give information about the sample's surface topography and composition.

FIGURE 3.5: Scanning Electron Microscope (SEM)

TABLE 3.1: Technical Specifications of Scanning Electron Microscope (SEM)

	Specifications
Light optical magnification	20 - 135x
Electron optical magnification range	80 - 100,000x
Resolution	< 17 nm
Digital zoom	Max 12x
High voltages	Adjustable range between 4,8 kV and 15 kV imaging and analysis mode
Sample Size	Up to 32 mm (Ø)
Sample Height	Up to 100 mm

3.4.1 Sample Preparation

3.4.1.1 Sectioning & Cutting

The first step in preparing a specimen to analyse the microstructure is to locate the area of interest. Cutting and sectioning is the most common technique to obtain the area of interest. Proper cutting will produce flat and cut close to the area of interest and minimal damage. In this project, the area of interest is the area where the group of fiber tows intersects, as shown in Figure 3.2. At this area is where the no-fiber triangles expected to be seen. After the area of interest is determined and marked, the CFRP is cut into smaller specimens as shown in Figure 3.8.

FIGURE 3.6: The Cutting Area of the CFRP

FIGURE 3.7: Samples before Cutting

FIGURE 3.8: Samples after Cutting

3.4.1.2 Grinding & Polishing

Grinding process was performed by using Grinder and Polisher machine model Metaserv 250 (Figure 3.9). The samples were grinded with SiC paper with running water. The SiC paper used ranged from the 240 grit to 1200 grit. The grinding process is done from coarsest to finest grit paper. This is to eliminate the scratches from the previous grinding stage.

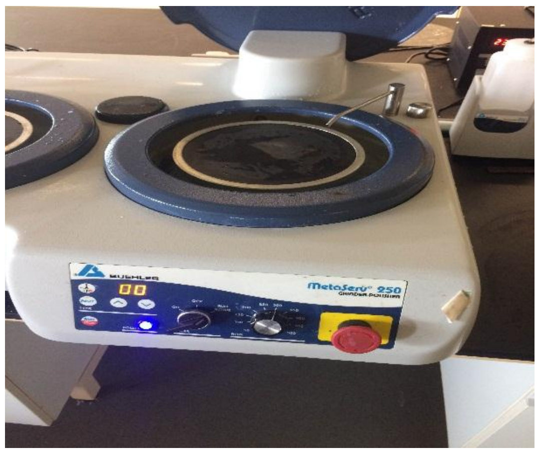

FIGURE 3.9: Metaserv 250

The grinding process is as follows:

1) SiC paper is placed on the grinding place, as shown in Figure 3.10, starting from 240 grit size. Water line is opened.

FIGURE 3.10: Placing of SiC Paper

2) The machine is switched on and the specimen is placed on the grinder, with the surface to be examined faced down (Figure 3.11).

FIGURE 3.11: Grinding of the Specimen

3) Grind for 1 to 2 minutes.
4) Steps 1 to 3 are repeated using different grit paper; 320, 400, 600, 800, 1200 grit size.
5) Close water line.
6) Specimen is then polished for around 1 to 2 minutes.

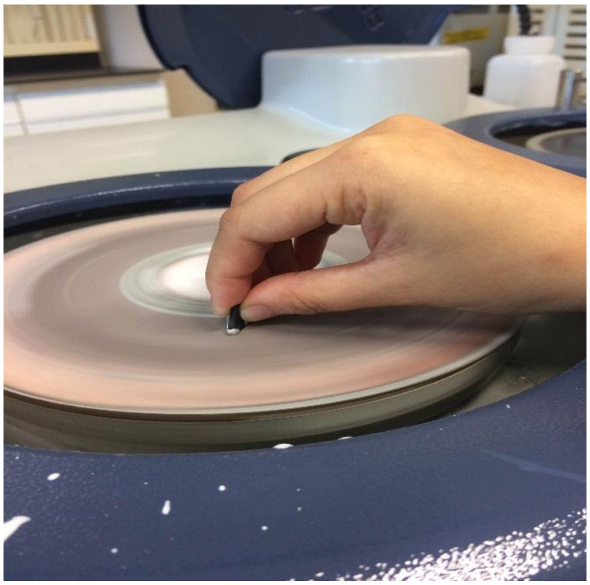

FIGURE 3.12: Polishing of the Specimen

3.4.1.3 Microstructure Test Procedure

The microstructure test is done based on the procedures as follows:

1) The sample is placed in the holder (Figure 3.13).

FIGURE 3.13: Placement of the Sample in the Holder

2) The holder height is adjusted (Figure 3.14).

FIGURE 3.14: Adjustment of the Holder Height

3) The holder is placed in the Phenom (Figure 3.15).

FIGURE 3.15: Placement of the Holder in the Phenom

4) The microstructure is observed from the desktop. The resolution can be adjusted accordingly.

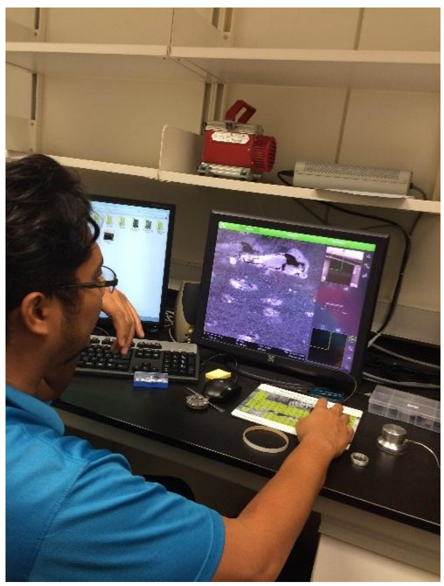

FIGURE 3.16: Observation of the Microstructure

3.5 Tensile Test (ASTM D638)

Tensile tests will be performed to measure the tensile properties like tensile strength, tensile modulus and elongation at break. The tensile tests will be measured by using a universal testing machine model AI-7000 M (Figure 3.17) according to ASTM D638. Table 3.2 shows the technical specifications of the machine [18].

FIGURE 3.17: AI-7000 M Universal Testing Machine [18]

TABLE 3.2: Technical Specifications of Universal Testing Machine [18*]*

	Specification
Capacity	1020 Kn
Load Resolution	1/200,000 (or 1/300,00 specified by user)
Stroke (exclude the grips)	1100 mm
Effective width	410 mm
Test Speed	0.001~1000 mm/min or 0.001~1500 mm/min
Sample Rate	1000 times/sec
Motor	AC Servo Motor
Power	1∲, 220V, 15A , 50Hz/60Hz or specified by user

The procedures of tensile test based on ASTM D638 are as follows:

1) 3 pieces of dog-bone shape specimens (Figure 3.18) are prepared according to ASTM D638 Standard.

2) Specimens are subjected to pulling speed of 20mm/min until failure.

3) Experiment are repeated 3 times to increase accuracy of results.

4) Stress-strain curve is then plotted and study the results to determine modulus of elasticity and maximum tension to failure.

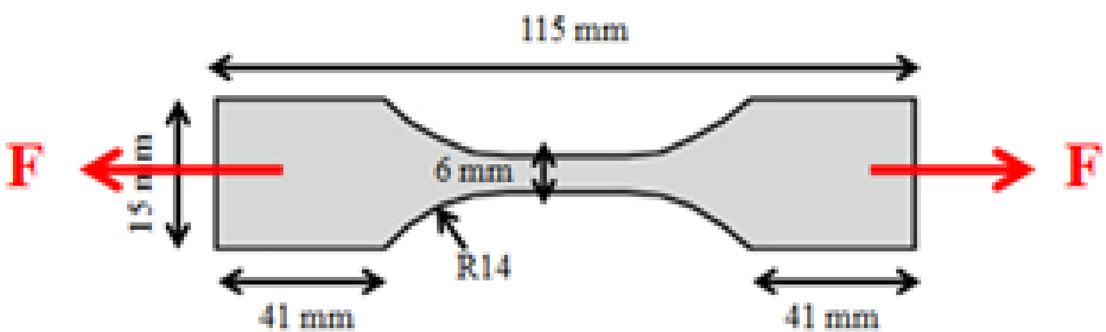

FIGURE 3.18: Dog-Bone Specimen Shape for Tensile Test (ASTM D638)

3.6 Compression Test (ASTM D695)

The procedures for compression test are as follows:

1) 3 pieces of 100mm CFWHP specimens are prepared according to ASTM D695 standard.

2) The specimen is placed in axial position (Figure 3.19).

3) Specimens are subjected to compression speed of 20mm/min until failure.

4) Experiment are repeated 3 times to increase accuracy of results.

5) Load-displacement curve is then plotted and study the results to determine energy absorption and maximum load to failure.

After obtaining load-displacement curves of all specimens, the maximum loads, mean loads and energy absorption values were calculated and reported for each test group.

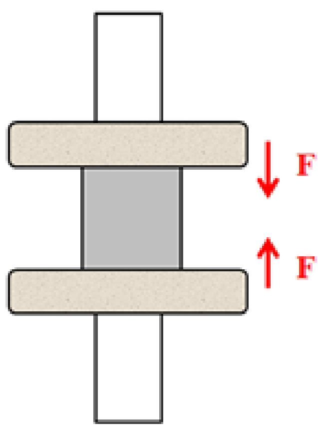

FIGURE 3.19: CFWHP Pipe Specimen in Axial Position Compression Test

3.7 Gantt Chart & Key Milestones

FYP I

No.	**Detail/Week**	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Title														
2	Preliminary research on carbon fiber wind to HDPE pipe (CFWHP)														
3	Study the effect of different arrangements of carbon fiber tow on the mechanical properties of CFWHP														
4	Submission of Extended Proposal							❖							
5	Detailed Research Work														
6	Proposal Defence									❖					
7	Perform microstructure test using SEM machine and analyse the results obtained														
8	Interim Draft Report Submission													❖	
9	Interim Report Submission														❖

Planning ❖ *Key Milestones*

The Gantt chart above shows the research activities and key milestones that would be conducted in Final Year Project I.

FYP II

No.	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Fabrication of CFWHP samples														
2	Sample preparation for tensile test and compression test														
3	Perform tensile test, and analyse the results obtained														
4	Submission of Progress Report							❖							
5	Perform compression test and analyse the results obtained														
6	Pre-Sedex										❖				
7	Submission of Draft Final Report											❖			
8	Submission of Dissertation (Soft Bound)												❖		
9	Submission of Technical Paper												❖		
10	Viva													❖	
11	Submission of Dissertation (Hard Bound)														❖

Planning ❖ *Key Milestones*

The Gantt chart above shows the research activities and key milestones that would be conducted in Final Year Project II.

CHAPTER 4

RESULTS & DISCUSSION

4.1 Microstructure Test Analysis (Surface Section)

Calculations for samples A1 (12k), B1 (12k + 6k) & C1 (6k)

Table 4.1 shows the calculations that have been obtained from the microstructure test for all the three samples for surface section. These calculations have been calculated using Equation (5).

TABLE 4.1: Calculations for 12k samples

Sample	Sample Height (m)	Base (m)	Area (m^2)
A1	0.003	3 X 0.000474	**4.266E-06**
B1	0.003	5 X 0.000211	**3.165E-06**
C1	0.003	7 X 0.000098	**2.058E-06**

Figure 4.1 shows the point of interest of the sample that underwent the microstructure test for surface section.

Formula to calculate area of void (surface section)

Area of void (m^2) = Base length (m) X Height of sample (m) (5)

Assumptions:-

Base (m) = **x**

For A1 = **3x**

For B1 = **5x**

For C1 = **7x**

FIGURE 4.1: Surface Section Point of Interest

Figure 4.2, 4.3, and 4.4 illustrates the hypothesis of carbon the carbon fiber tow arrangement. X represents the length of void area.

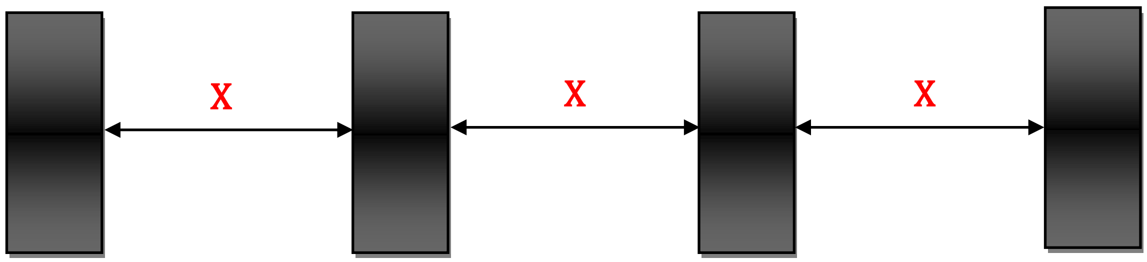

FIGURE 4.2: 12k Fiber Tow Sample Arrangement

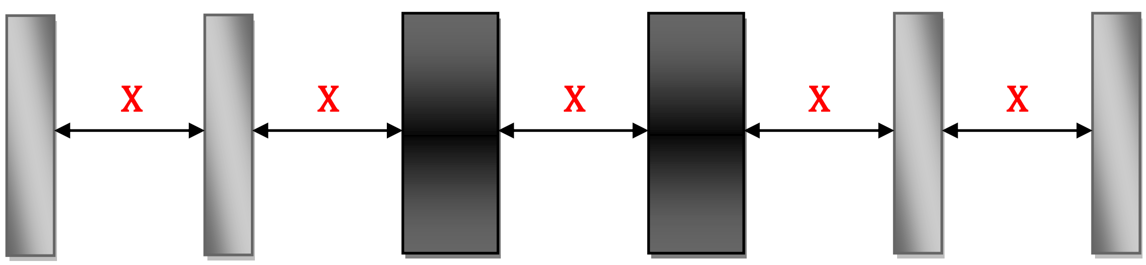

FIGURE 4.3: 12k + 6k Fiber Tow Sample Arrangement

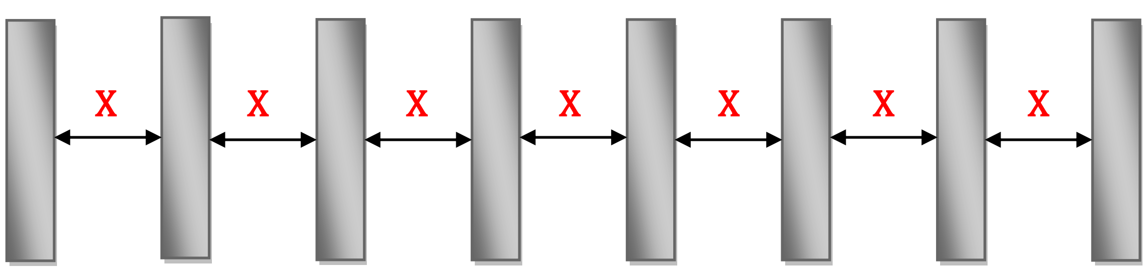

FIGURE 4.4: 6k Fiber Tow Sample Arrangement

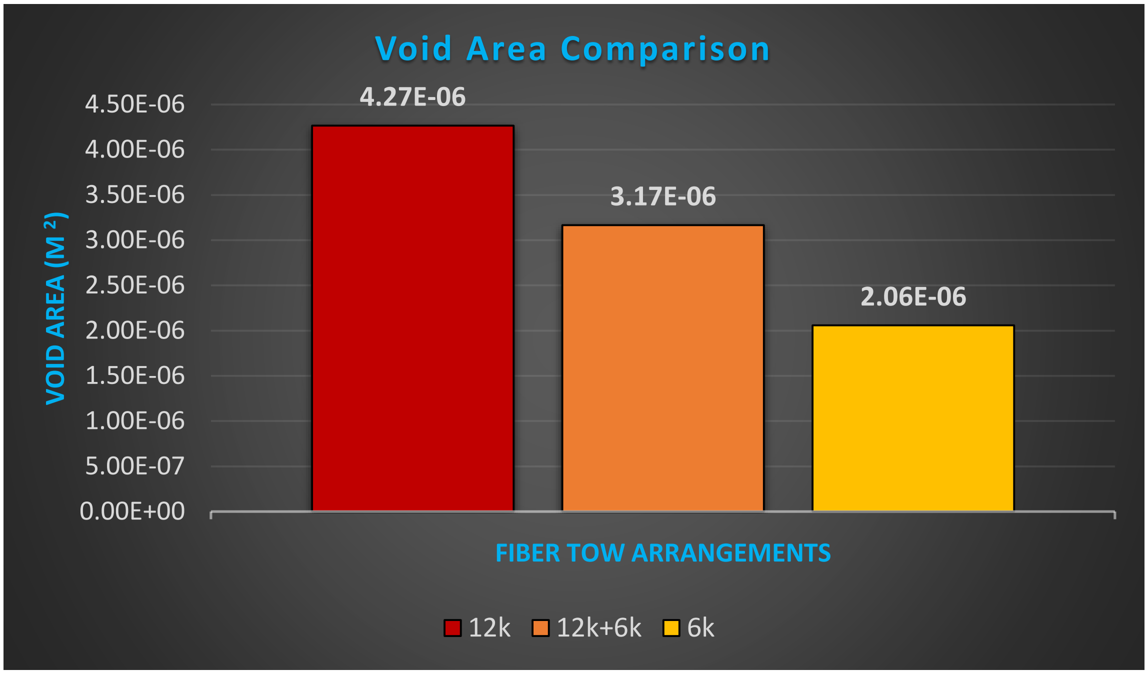

FIGURE 4.5: Comparison of Void Areas (Surface Section) using Different Fiber Tow Arrangements

The comparison chart above (Figure 4.5) justifies that the area of voids for surface section for 6k fiber tow sample is the smallest when compared with the 12k fiber tow sample and the 12k + 6k fiber tow sample. Table 4.1 shows the mathematical proof to support that statement. This shows that the increment of fiber content lead to the decrease in the area of voids. Furthermore, during the fabrication of the samples, the bandwidth of both types of sample are maintained the same. This leads to the increase in space between each tow of the CFWHP samples.

Sample using 12k fiber tow arrangements

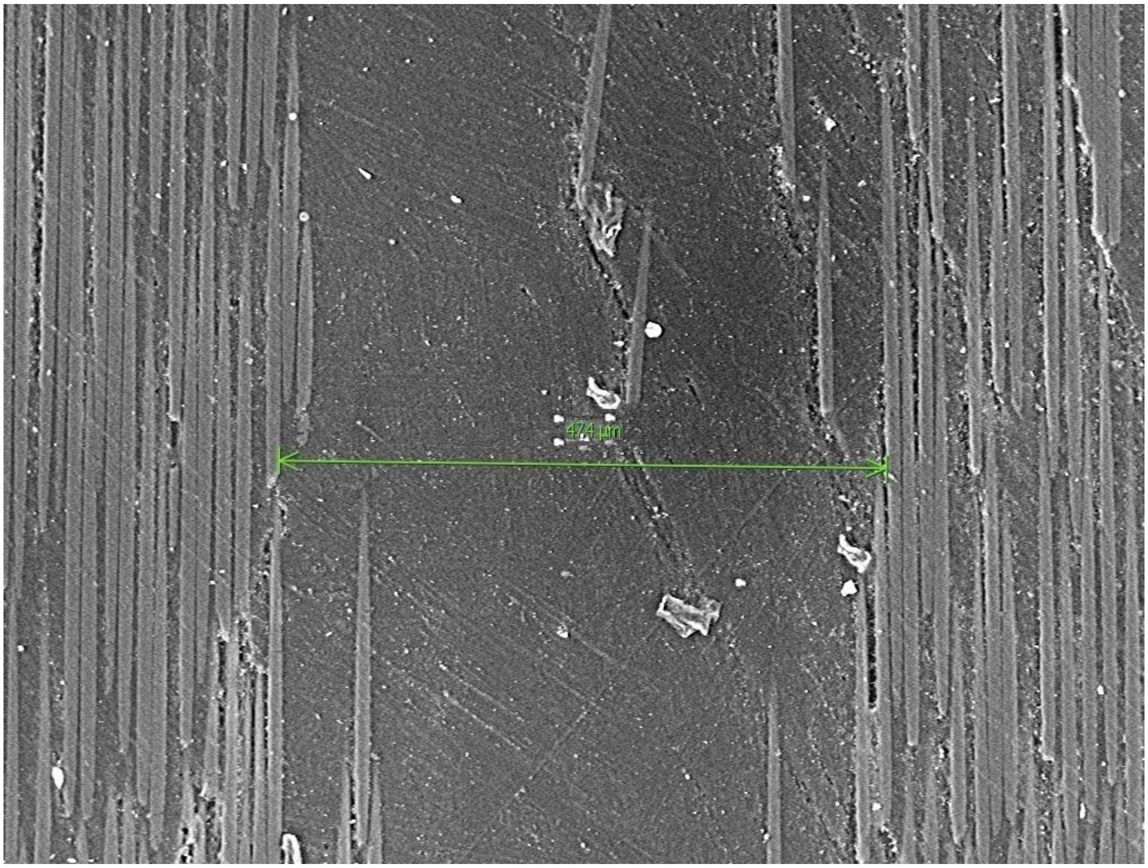

FIGURE 4.6: Surface Void Formation for Sample A1

Figure 4.6 above shows the SEM results obtained from the microstructure test for the 12k sample.

Sample using 12k + 6k fiber tow arrangements

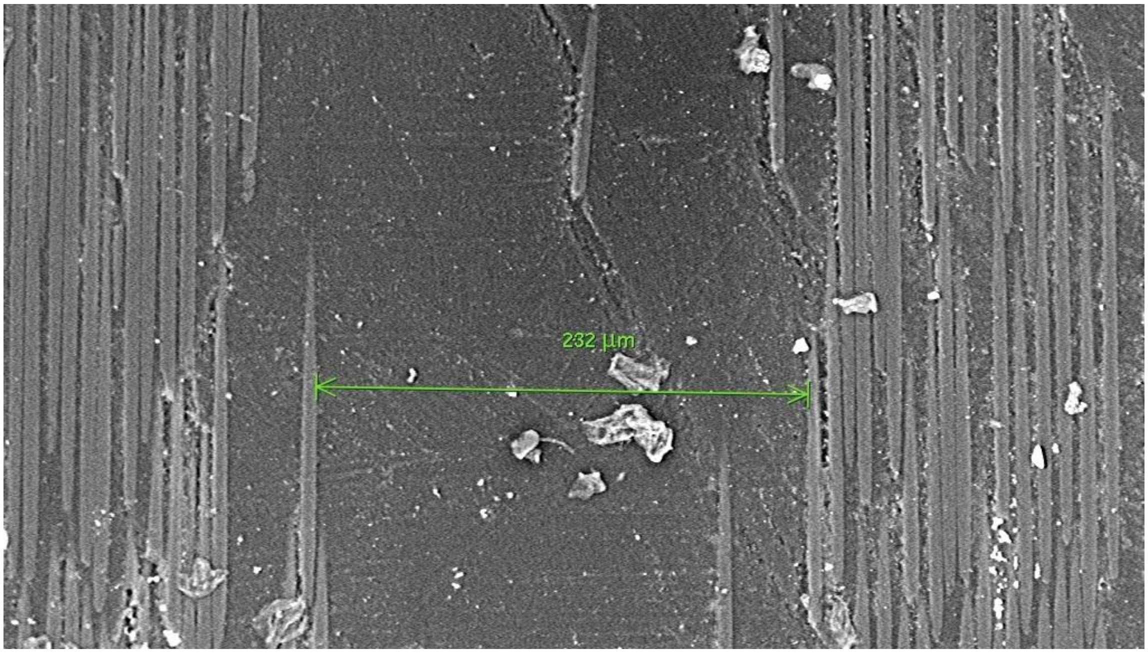

FIGURE 4.7: Surface Void Formation for Sample B1

Figure 4.7 above shows the SEM results obtained from the microstructure test for the 12k + 6k sample

Sample using 6k fiber tow arrangements

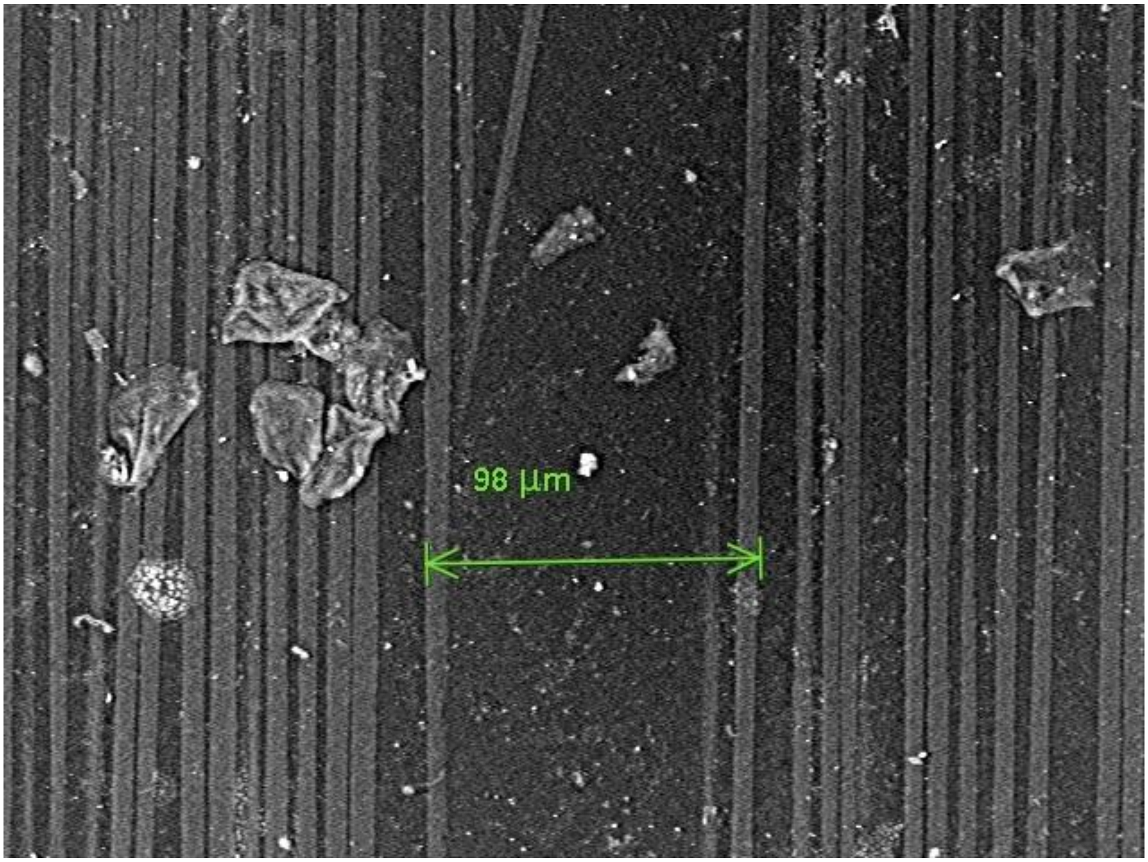

FIGURE 4.8: Surface Void Formation for Sample C1

Figure 4.8 above shows the SEM results obtained from the microstructure test for the 6k sample.

4.2 Microstructure Test Analysis (Cross Section)

Table 4.2, 4.3 and 4.4 shows the result obtained from the microstructure test for all the three samples for cross section. The calculations have been calculated using Equation (6).

Calculations for samples A1 & A2 (12k)

TABLE 4.2: Calculations for 12k samples

Sample	**Average Height (m)**	**Base (m)**	**Area (m^2)**
A1	0.000029550	0.000369000	1.0904E-08
A2	0.000043075	0.000231000	9.9503E-09
Average			**1.0427E-08**

Calculations for samples B1 & B2 (12k + 6k)

TABLE 4.3: Calculations for 12k samples

Sample	**Average Height (m)**	**Base (m)**	**Area (m^2)**
B1	0.000022150	0.000276000	6.1134E-09
B2	0.000026750	0.000474000	1.2680E-08
Average			**9.3965E-09**

Calculations for samples C1 & C2 (6k)

TABLE 4.4: Calculations for 6k samples

Sample	Average Height (m)	Base (m)	Area (m^2)
C1	0.000027175	0.000432000	1.17396E-08
C2	0.000022400	0.000275000	6.1600E-09
Average			**8.9498E-09**

Formula to calculate area of void (cross section)

Area of void (m^2) = Average height (m) X Base length (m) (6)

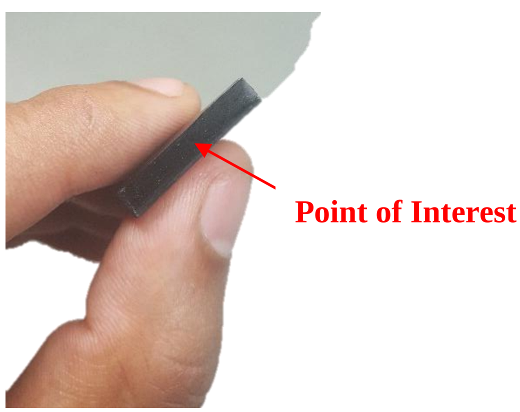

FIGURE 4.9: Cross Section Point of Interest

Figure 4.9 shows the point of interest of the sample that underwent microstructure test for cross section.

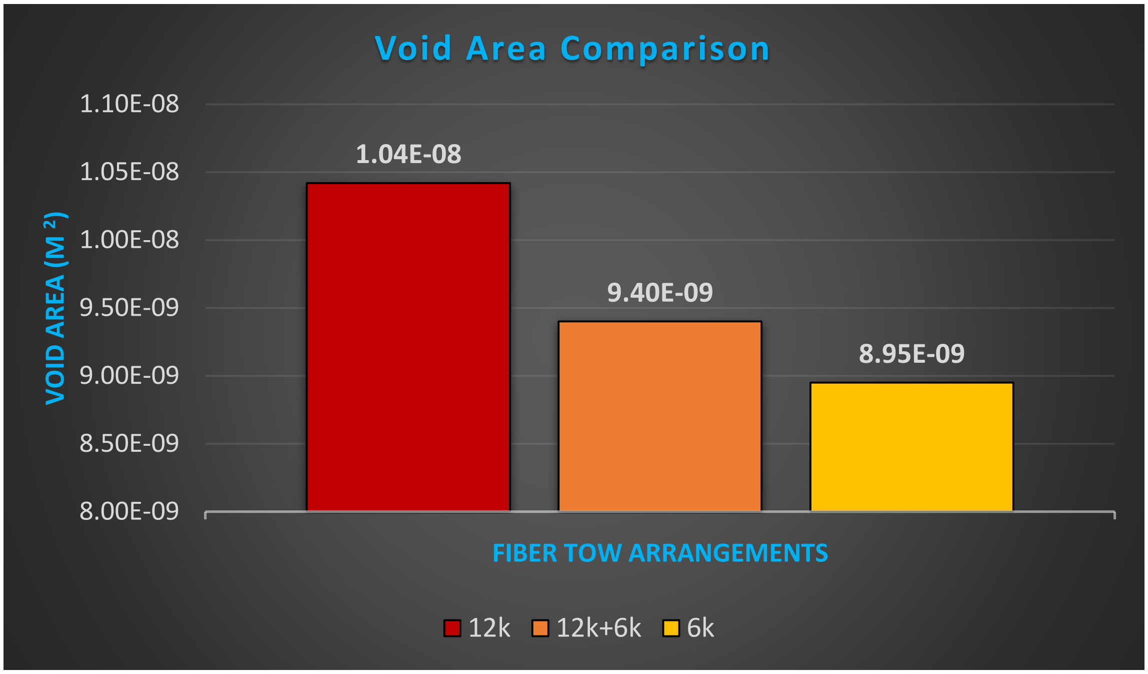

FIGURE 4.10: Comparison of Void Areas (Cross Section) using Different Fiber Tow Arrangements

The comparison chart above (Figure 4.10) justifies that the area of voids for cross section of 6k fiber tow sample is the smallest when compared with the 12k fiber tow sample and the 12k + 6k fiber tow sample. Table 4.2, 4.3 and 4.5 shows the mathematical proof to support that statement. This shows that the increment of fiber content lead to the decrease in the area of voids. Furthermore, during the fabrication of the samples, the bandwidth of both types of sample are maintained the same. This leads to the increase in space between each tow of the CFWHP samples.

Samples using 12k fiber tow arrangements

The samples have been labelled as A1 respectively.

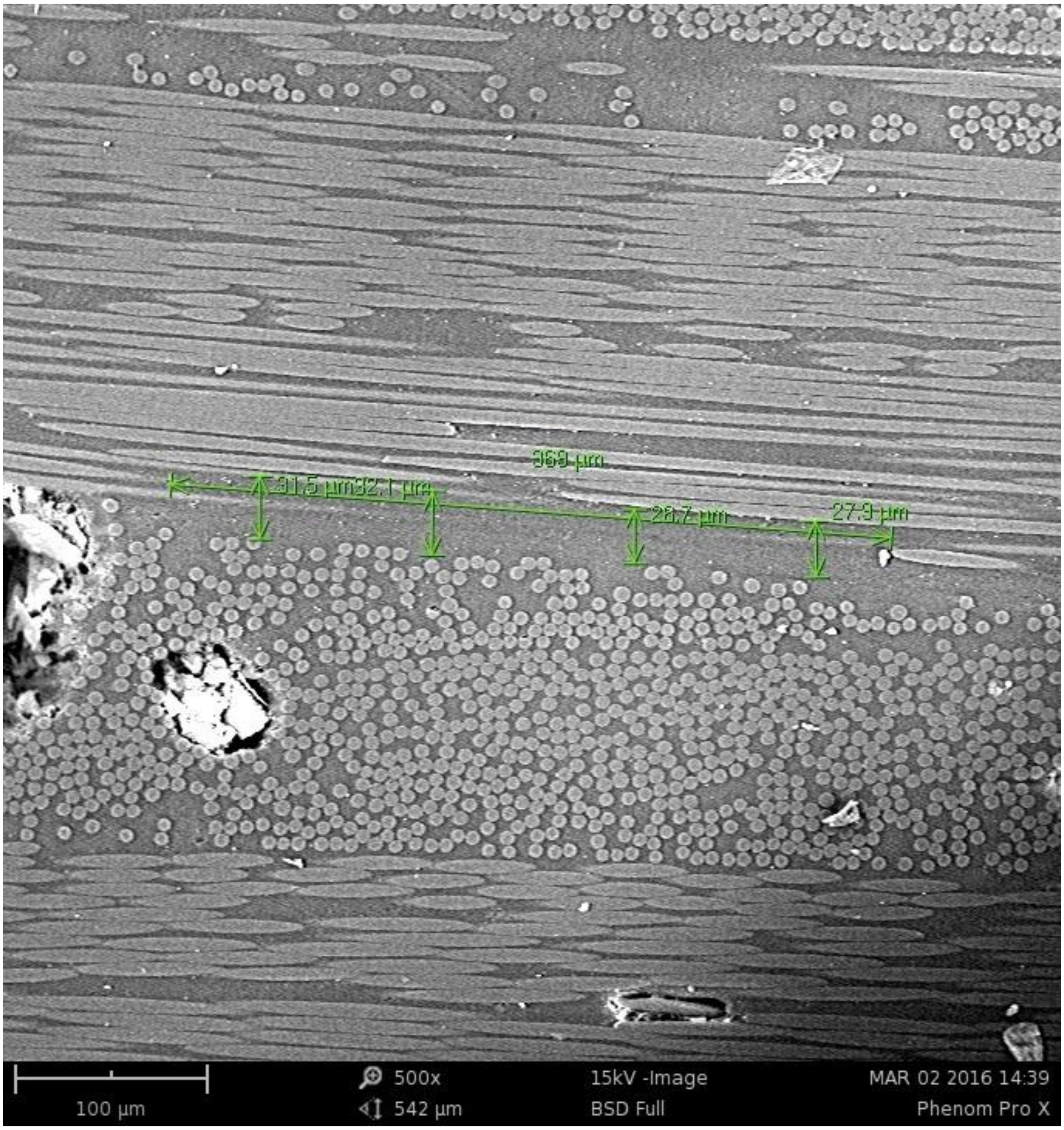

FIGURE 4.11: Cross Section Void Formation for Sample A1

Figure 4.11 above shows the SEM results obtained from the microstructure test for the 12k sample.

Samples using 12k + 6k fiber tow arrangements

The samples have been labelled as B2.

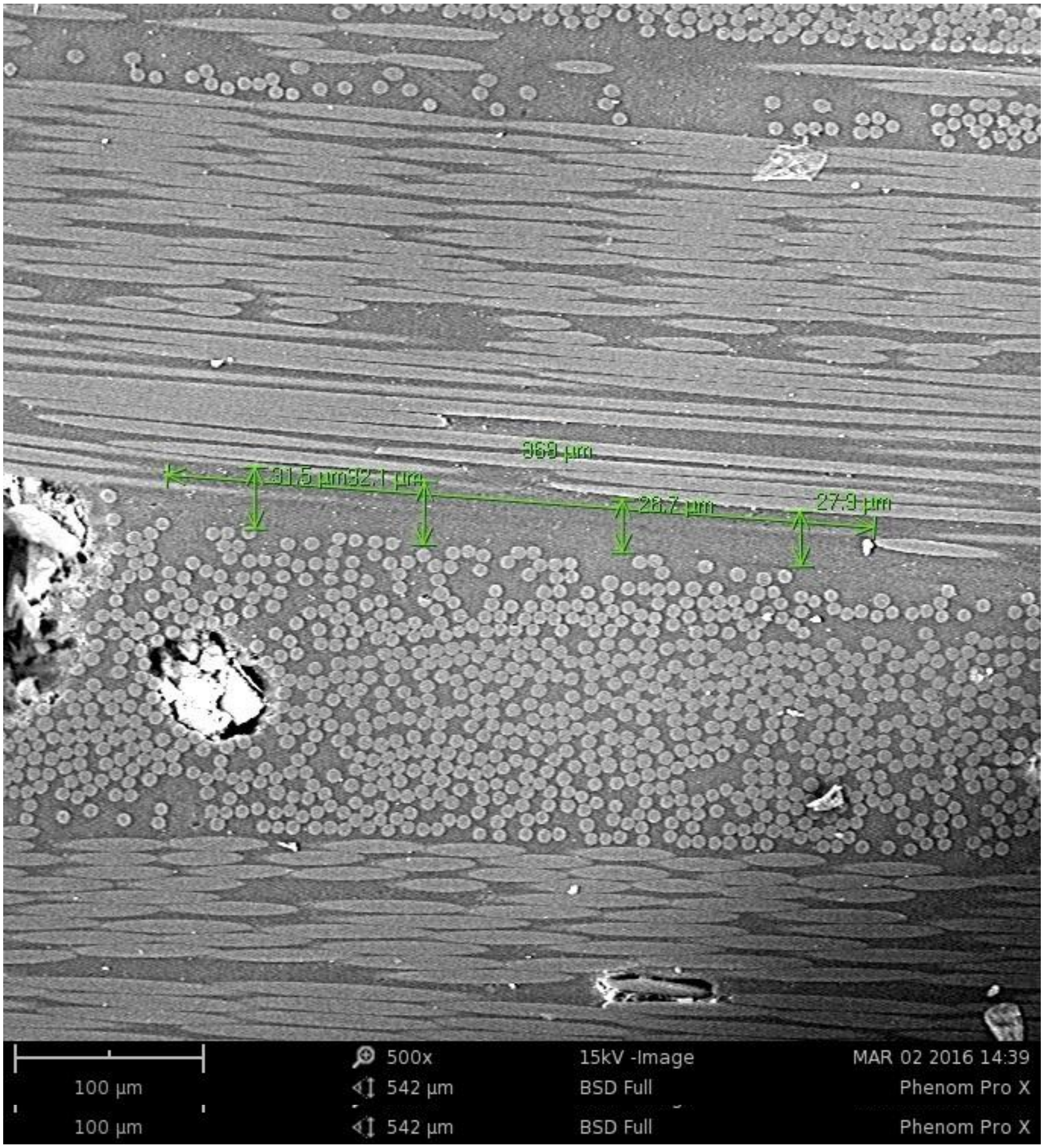

FIGURE 4.12: Cross Section Void Formation for Sample B2

Figure 4.12 above shows the SEM results obtained from the microstructure test for the 12k +6k sample.

Samples using 6k fiber tow arrangements

The samples have been labelled as C2.

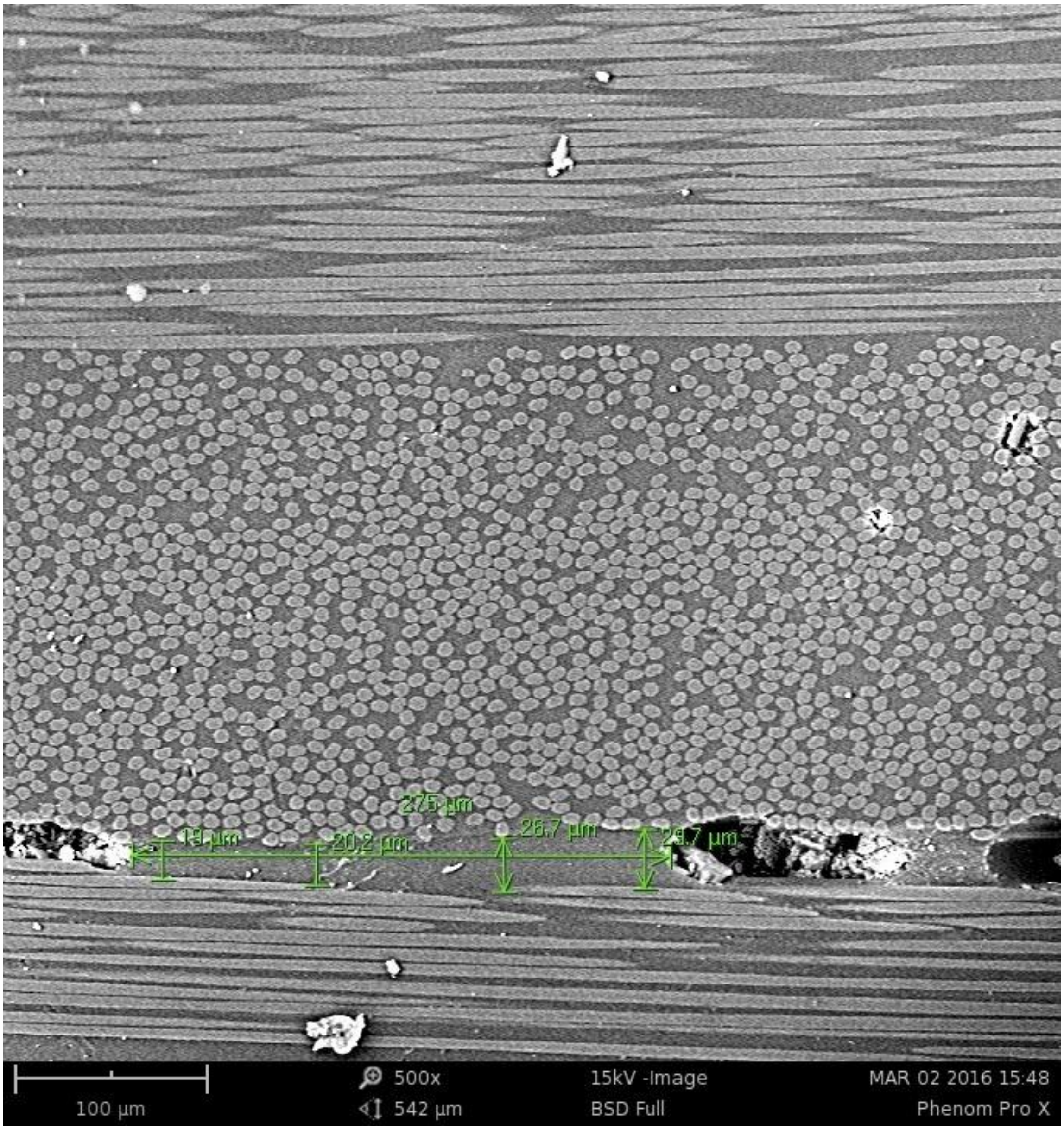

FIGURE 4.13: Cross Section Void Formation for Sample C2

Figure 4.13 above shows the SEM results obtained from the microstructure test for the 6k sample.

4.3 Tensile Test (ASTM D638)

TABLE 4.5: Tensile Test Result Tabulation

Sample	Failure Mode	Original Length	Average Final Length	Average Max. Load	Tensile Stress
12k (A1, A2 & A3)	Very brittle for carbon fiber layer, surface of failure is even without much resistance towards the pulling force	115mm	120mm	1,127.67 N	**7.81 MPa**
12k + 6k (B1, B2 & B3)	Slightly brittle for carbon fiber layer, surface of failure is not so even with slight resistance towards the pulling force	115mm	120mm	1,383.67 N	**10.07 MPa**
6k (C1, C2 & C3)	Brittle for carbon fiber layer, surface of failure is not even with resistance towards the pulling force	115mm	121mm	1,891.33 N	**12.66 MPa**

The table above (Table 4.5) tabulates the results obtained from the tensile test conducted. 3 samples were tested for each different carbon fiber tow arrangement. From the obtained results, an average reading has been calculated for all the 3 different fiber tow arrangements. Samples A which are the 12k samples displays an even surface breakage while the B samples which are the 12k + 6k samples shows a slightly uneven surface breakage. However, the C samples which are the 6k samples shows a very uneven surface breakage. This is due to the stronger 6k samples' ability to resist the pulling more efficiently when compared to the 12k + 6k samples (B) and also the 12k samples (A).

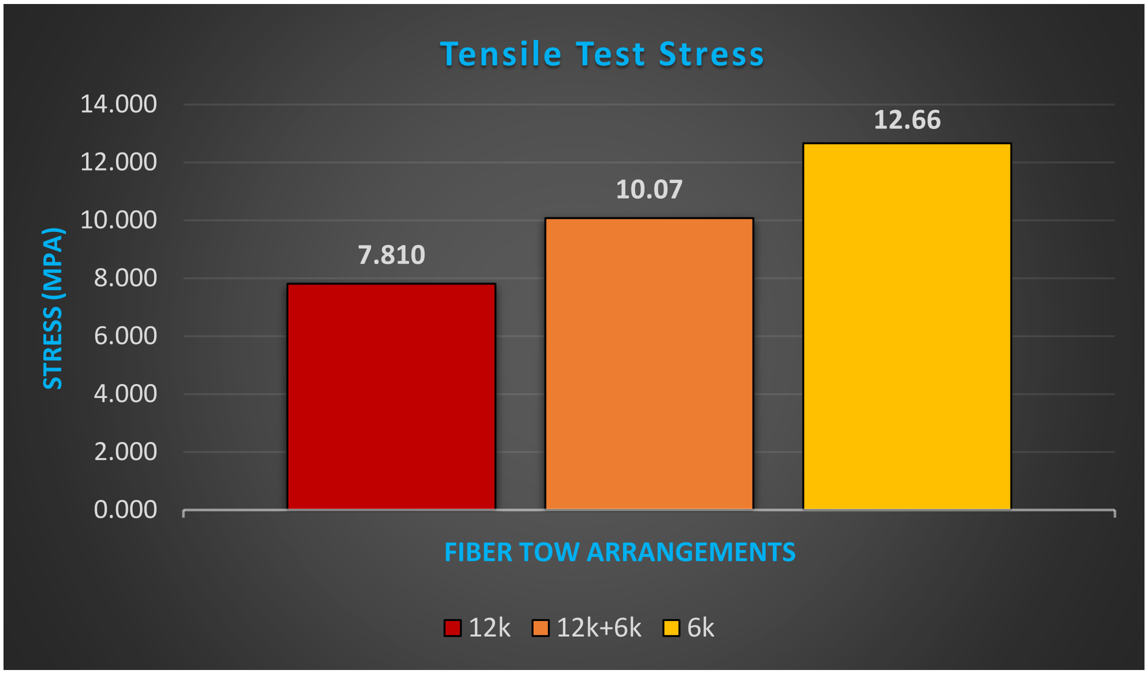

FIGURE 4.14: Comparison of Tensile Test Stress Loads using Different Fiber Tow Arrangements

The chart above (Figure 4.14) clearly shows the tensile stresses for all the 3 samples. The strongest sample being the 6k sample (C), followed by the 12k + 6k sample (B) and finally the 12k sample (A). This further proves the theory of where the void area plays a role in the strength of the material. Smaller void areas results in a stronger material. Based on the results obtained from the microstructure test, the 6k samples (C) had the smallest void area followed by the 12k + 6k sample (B) and finally the 12k sample (A). The figures below shows the stress-strain curve of all the samples involved in the tensile test. The results clearly shows that the 6k samples (C) require higher stress value in order to reach its failure point when compared to the 12k + 6k samples (B) and the 12k samples (A). Below are images of the sample after undergoing tensile tests.

Universiti Teknologi Petronas

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Tensile Test Report

Material :Composite Carbon Fibre

Test Method :ASTM D638

Test Speed : 20.000 mm/min

Test No.	Thickness mm	Width mm	Max. Load N	Elastic Modulus MPa	T.Strength MPa	Y.Load N	Y.Strength MPa	Elongation@Break %
1	9.500	15.00	1113	206	7.81	-	-	4.72
---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---
Average	9.500	15.00	1113	206	7.81	0.000	0.000	4.72
$SD_{(N-1)}$	0.000	0.00	0	0	0.00	0.000	0.000	0.00

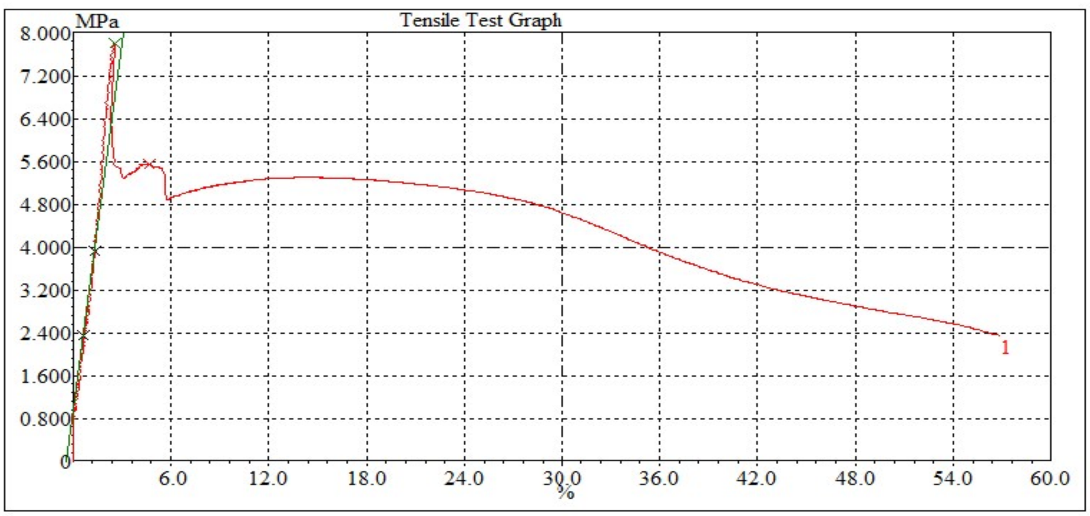

FIGURE 4.15: Stress-Strain Curve for Sample A (12k)

Due to certain machine limitations, the graphs obtained from tensile test are not as expected. To get better and more accurate results, better machines are recommended to be used in the future.

Universiti Teknologi Petronas

MECHANICAL ENGINEERING DEPARTMENT
BANDAR SERI ISKANDAR
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PERAK.

UNIVERSITI TEKNOLOGI PETRONAS

Tensile Test Report

Material :Composite Carbon Fibre
Test Method :ASTM D638

Test Speed : 20.000 mm/min

Test No.	Thickness mm	Width mm	Max. Load N	Elastic Modulus MPa	T.Strength MPa	Y.Load N	Y.Strength MPa	Elongation@Break %
1	9.000	15.00	1406	366	10.41	-	-	14.38
---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---
Average	9.000	15.00	1406	366	10.41	0.000	0.000	14.38
SD(N-1)	0.000	0.00	0	0	0.00	0.000	0.000	0.00

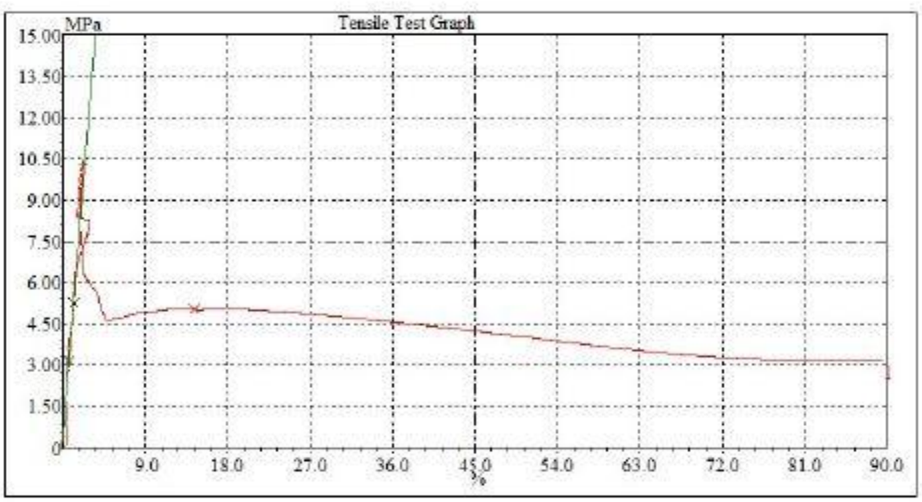
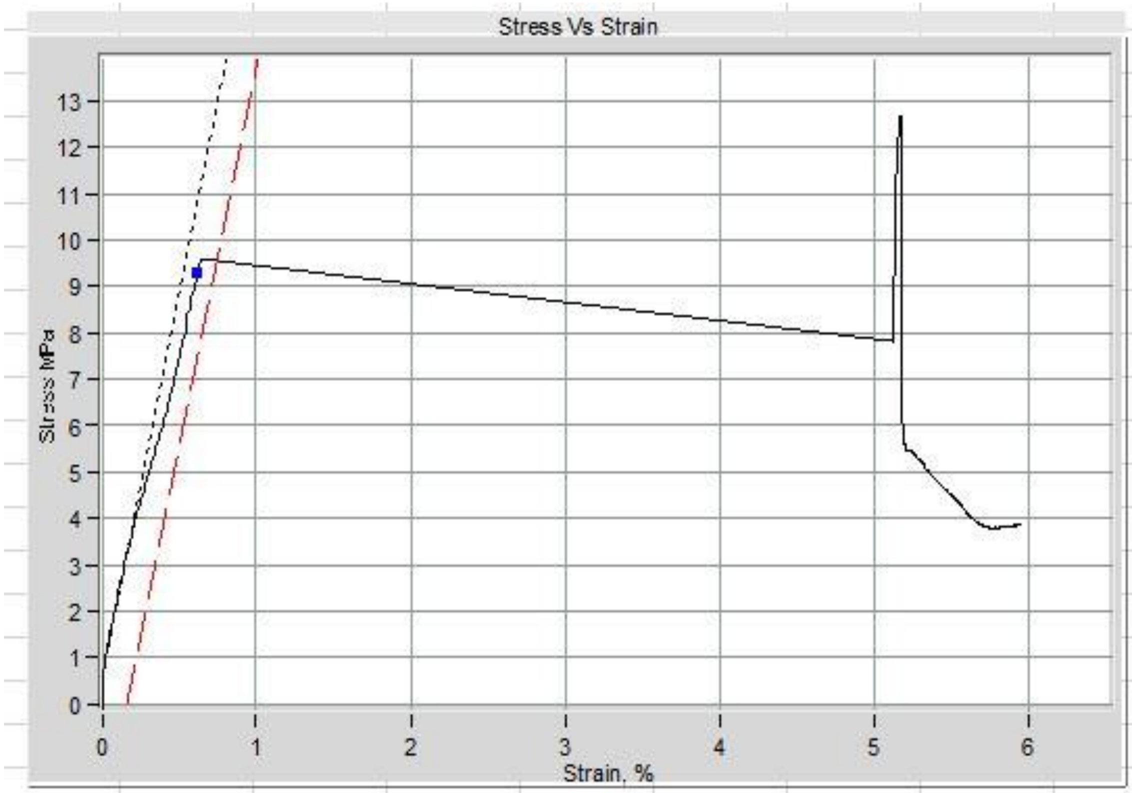


FIGURE 4.16: Stress-Strain Curve for Sample B (12k + 6k)

Due to certain machine limitations, the graphs obtained from tensile test are not as expected. To get better and more accurate results, better machines are recommended to be used in the future.



Peak Stress:	12.656	MPa	
Peak Load:	1.898	kN	
0.2% Offset Yield Stress:	7.833	MPa	
Yield Strain:	5.126	%	
Yield Load:	1.175	kN	
Modulus:	1.642	GPa	238.107 ksi

FIGURE 4.17: Stress-Strain Curve for Sample C (6k)

Due to certain machine limitations, the graphs obtained from tensile test are not as expected. To get better and more accurate results, better machines are recommended to be used in the future.

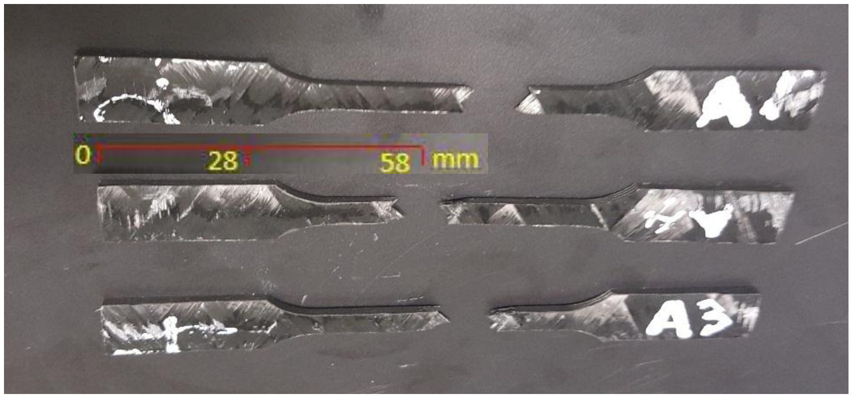


FIGURE 4.18: Samples A (12k) after Tensile Test

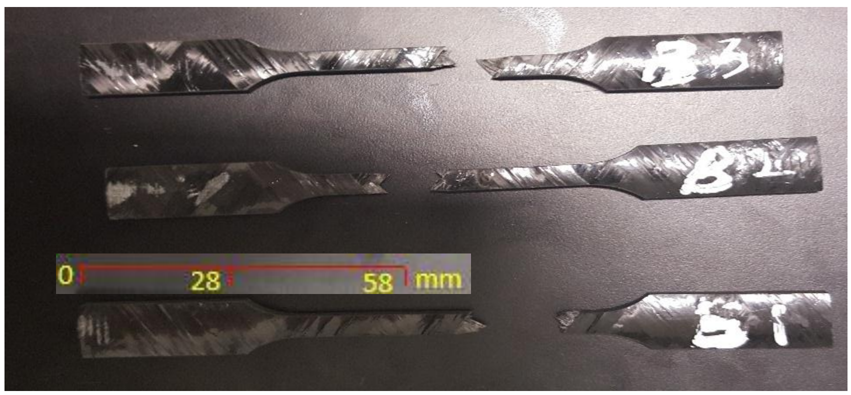


FIGURE 4.19: Samples B (12k + 6k) after Tensile Test

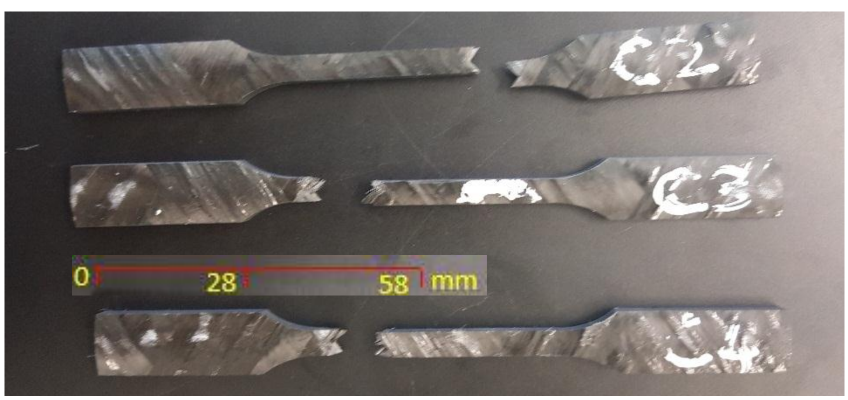


FIGURE 4.20: Samples C (6k) after Tensile Test

Figure 4.18, 4.19 and 4.20 shows the three samples after undergoing tensile test. As we can see, the matrix fails first and later on followed by the carbon fiber reinforcement. Hence, the failure modes are achieved as the figure above.

4.4 Compression Test (ASTM D695)

Table 4.6 shows the result obtained from the compression test for all three samples. The calculations have been calculated using Equation (7) and Equation (8).

TABLE 4.6 : Compression Test Result Tabulation

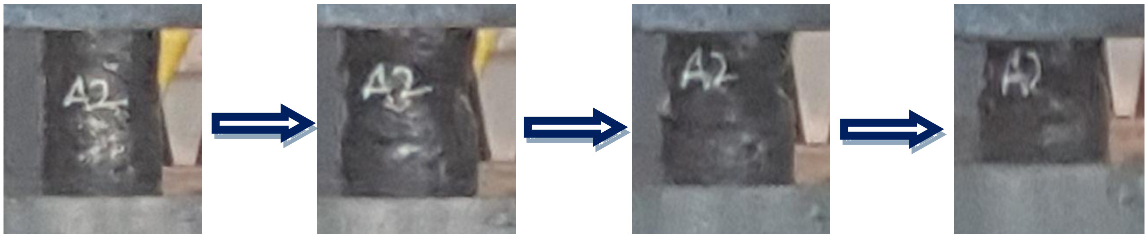
Sample	**Original Length**	**Average Final Length**	**Average Max. Load**	**Average Mean Load**	**Energy Absorption**	**Specific Energy Absorption**
12k (A1, A2 & A3)	100mm	60mm	**95.60 kN**	**57.10 kN**	**2.28 kNm**	**10.20 J/kg**
12k + 6k (B1, B2 & B3)	100mm	60mm	**106.55 kN**	**68.48 kN**	**2.74 kNm**	**12.23 J/kg**
6k (C1, C2 & C3)	100mm	60mm	**117.48 kN**	**79.42 kN**	**3.18 kNm**	**14.18 J/kg**

Formula to calculate Energy Absorption

Energy Absorption (J/kg) = Average Mean Load (kN) X (D_f – D_i) (m) (7)

Formula to calculate Specific Energy Absorption

Specific Energy Absorption (kN) = Energy Absorption (kNm) ÷ Mass (g) (8)



Stage 1 *Stage 2* *Stage 3* *Stage 4*

<u>Stage 1</u>

Both ends of sample start to experience axial compression force. It starts to transfer the load force from both ends towards the center part of the sample.

<u>Stage 2</u>

Compression force at both ends of the sample reached maximum and eventually the center part of the sample starts to experience deformation. “Crack” sound starts to appear as it signifies the breaking of the outer layer of carbon fiber.

<u>Stage 3</u>

“Crack” sound frequency increases to show that more and more fibers are breaking at the outer layer. Load force starts to be transferred from outer layer of carbon fiber towards inner layer of HDPE pipe.

<u>Stage 4</u>

At this final stage, the outer layer of carbon fiber experience cracks and defragmentation until it eventually fails. HDPE pipe at the inner layer continues to experience the load force until eventually deforming and exceeding its elastic limits.

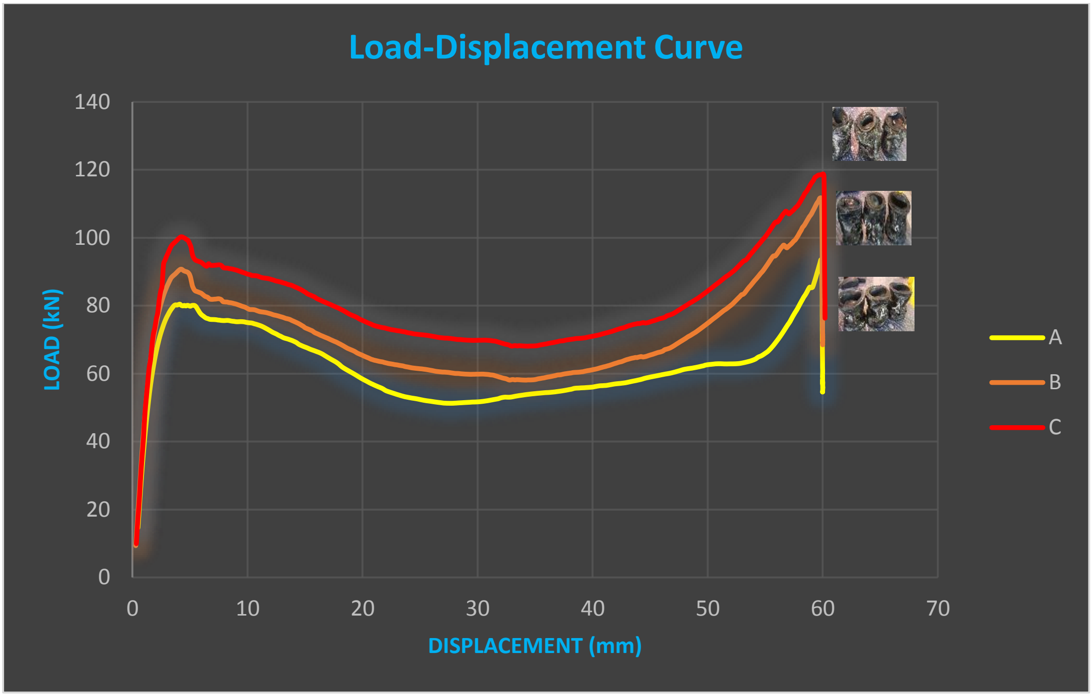


FIGURE 4.21: Compression Test Load-Displacement Curve

Figure 4.21 shows the load-displacement curve of 12k sample (A) versus 12k+6k sample (B) and 6k sample (C) in compression test. Result clearly shows that 6k sample has larger area under the curve profile as compared to 12k+6k sample and 12k sample which contributed to higher energy absorption value as recorded in table 4.6. The graph also shows that 6k sample can tolerate with much higher load before it eventually fails as compared to 12k+6k sample. This further proves the theory of the smaller void area sample having the highest strength, as found in the microstructure test, the 6k sample has the smallest void area. Below are images of the samples after undergoing the compression test.

Figure 4.22 and 4.23 shows the 12k samples after undergoing compression test. As can be observed, the samples undergo folding of two lobes in order to defend the HDPE layer inside.

FIGURE 4.22: Side View of Samples A after Compression Test

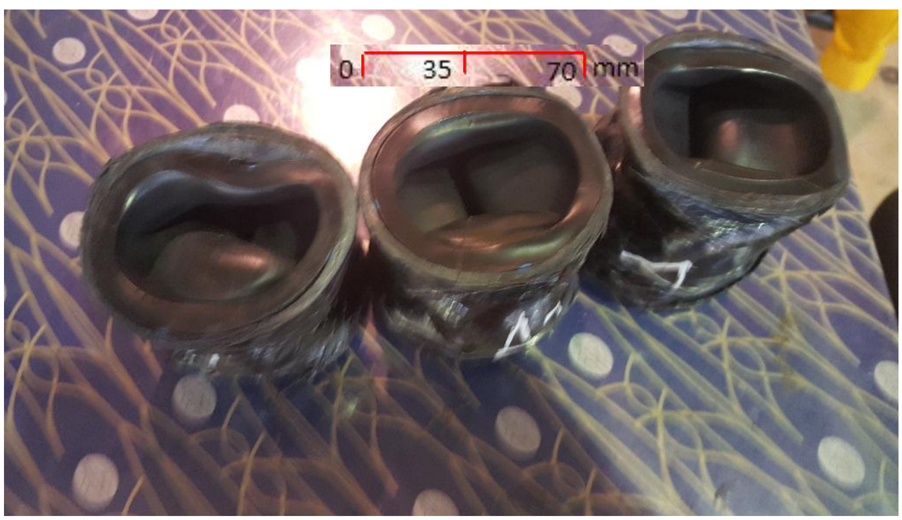


FIGURE 4.23: Top View of Samples A after Compression Test

Figure 4.24 and 4.25 shows the 12k + 6k samples after undergoing compression test. As can be observed, the sample undergoes folding of 2 lobes in order to defend the HDPE layer inside.

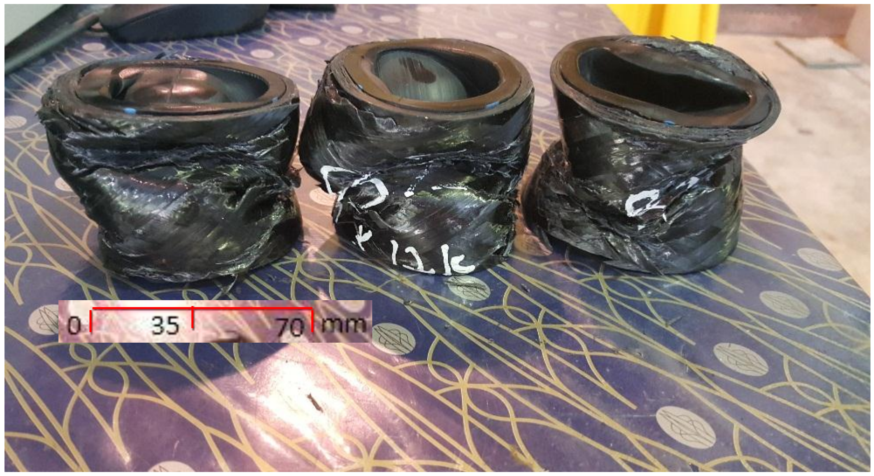


FIGURE 4.24: Side View of Samples B after Compression Test

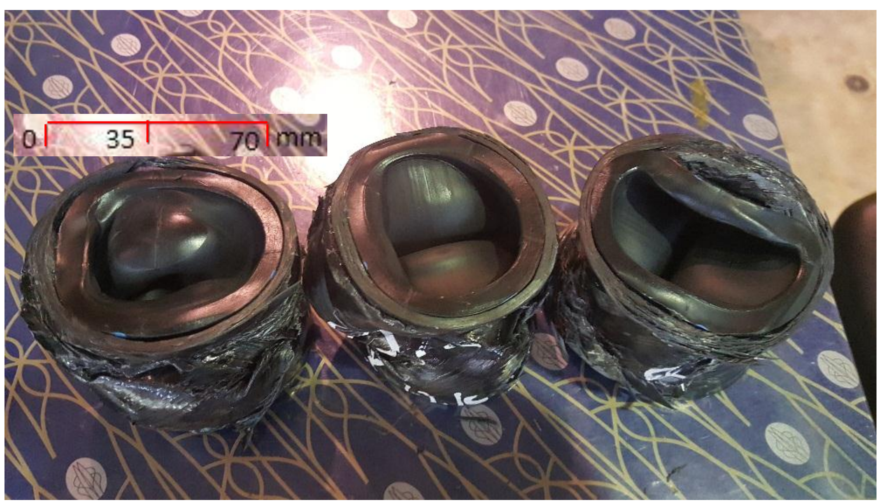


FIGURE 4.25: Top View of Samples B after Compression Test

Figure 4.26 and 4.27 shows the 6k samples after undergoing compression test. As can be observed, the sample undergoes folding and fragmentation. In order to defend the HDPE the carbon fiber undergoes folding, once the carbon fiber can no longer sustain the force, the HDPE layer inside starts to expand which causes the carbon fiber to undergo fragmentation. This explains the high energy absorptions values for the 6k samples.

FIGURE 4.26: Side View of Samples C after Compression Test

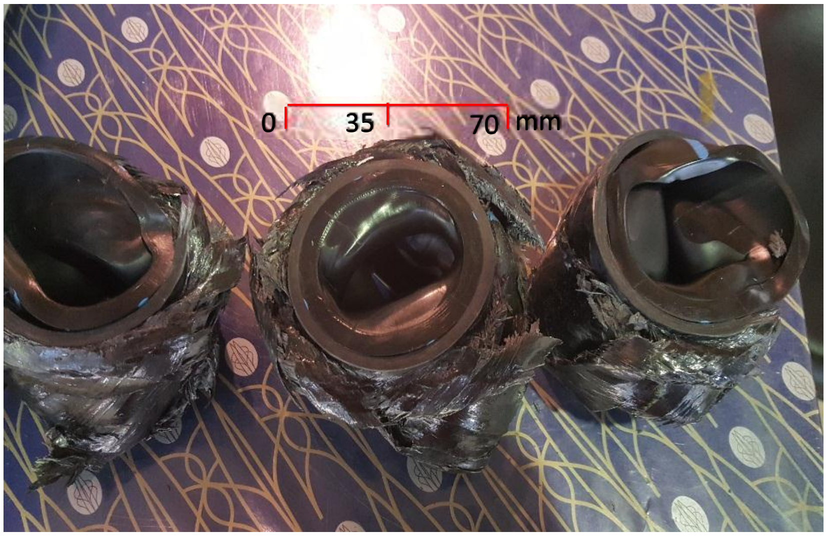


FIGURE 4.27: Top View of Samples C after Compression Test

CHAPTER 5
CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

The first objective of this project was to study how various sizes of carbon fiber tow arrangements affect the level of enhancement of mechanical properties the carbon fiber wind to HDPE pipe (CFWHP). Microstructure test analysis showed that the void area of 6k (Samples C) CFRP is smaller than the void areas of the 12k (Samples A) CFRP and the 12k + 6k (Samples B) CFRP. This is due to the higher fiber content in the 6k CFRP. Hence it is observed that the different arrangements of fiber tow with the maintained number of tows and bandwidth size does cause changes in the formation of voids.

From the tensile test, it has been concluded that the strongest sample is the 6k sample (C), followed by the 12k + 6k sample (B) and finally the 12k sample (A). This further proves the theory of where the void area plays a role in the strength of the material. Smaller void areas results in a stronger material. Based on the results obtained from the microstructure test, the 6k samples (C) had the smallest void area followed by the 12k + 6k sample (B) and finally the 12k sample (A). As for the stress-strain curve obtained of all the samples involved in the tensile test, the results clearly shows that the 6k samples (C) require higher stress value in order to reach its failure point when compared to the 12k + 6k samples (B) and the 12k samples (A).

As for the compression test, the load-displacement curve of 12k sample (A) versus 12k+6k sample (B) and 6k sample (C) in compression test. Result clearly shows that 6k sample has larger area under the curve profile as compared to 12k+6k sample and 12k sample which contributed to higher energy absorption value as recorded in table 4.6. The graph also shows that 6k sample can tolerate with much higher load before it eventually fails as compared to 12k+6k sample. This further proves the theory of the smaller void area sample having the highest strength, as found in the microstructure test, the 6k sample has the smallest void area.

In a nutshell, the parties involved in the oil and gas industry are now looking into other alternatives when it comes to pipelines. This is because, the existing commercial metallic pipelines are very much prone to corrosion. So, the solution that has been proposed is to bring in non-metallic pipelines into play. To be precise, composite material pipelines. The composite material chosen for this solution is carbon fiber reinforced polymer (CFRP). Non- metallic pipelines are corrosion resistant and also have a lifespan of around 50 years or so. Tests has been done in order to show that the usage of non-metallic pipelines brings in far more advantages than the commercial steel pipelines.

5.2 Recommendation

Further research with CFRP with less than 6 fiber tows with different size of fiber tows to fill in the no-fiber triangle as compared to the 12k, 12k + 6k, and 6k fiber tow samples after analyzing the results obtained from the microstructure test and also the tensile test. For instance, 3k carbon fiber tow samples maybe used. A sample which has 16 fiber tows of 3k carbon fiber and a sample of 8 fiber tows of 3k carbon fiber and 4 fiber tows of 6k carbon fiber can be put through testing to study even further the effect of different carbon fiber tow arrangements has on the mechanical properties of CFWHP. Besides that, better machines could be used for the microstructure test. The current SEM machine used for this project has its limitations when measuring the length of void. Some of the voids proved to be too long for the machine to measure. Hence, a better machine may prove to provide a more accurate result.

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APPENDICES

Tensile Test Sample 12k

Universiti Teknologi Petronas

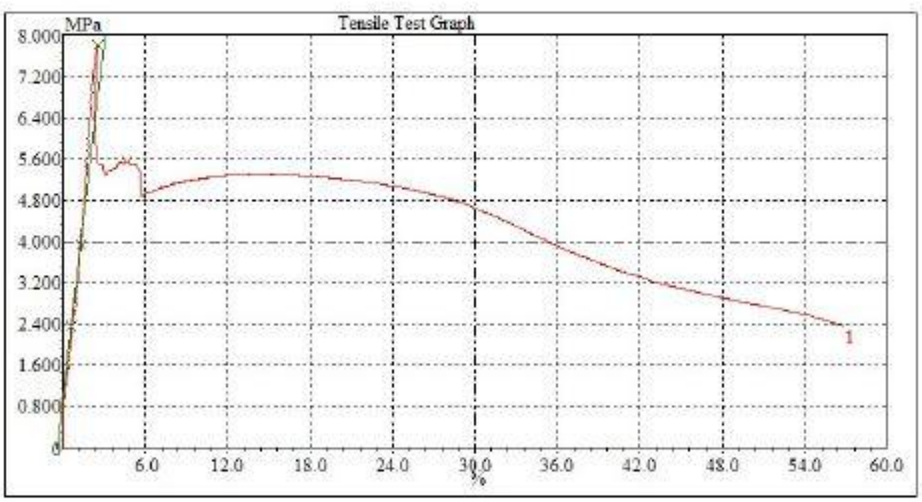
MECHANICAL ENGINEERING DEPARTMENT
BANDAR SERI ISKANDAR
31750, TRONOH
PERAK

Tensile Test Report

Material :Composite Carbon Fibre
Test Method :ASTM D638

Test Speed : 20.000 mm/min

Test No.	Thickness mm	Width mm	Max. Load N	Elastic Modulus MPa	T.Strength MPa	Y.Load N	Y.Strength MPa	Elongation@Break %
1	9.500	15.00	1113	206	7.81	-	-	4.72
---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---
Averag	9.500	15.00	1113	206	7.81	0.000	0.000	4.72
$SD^{(N-1)}$	0.000	0.00	0	0	0.00	0.000	0.000	0.00



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31750, TRONOH
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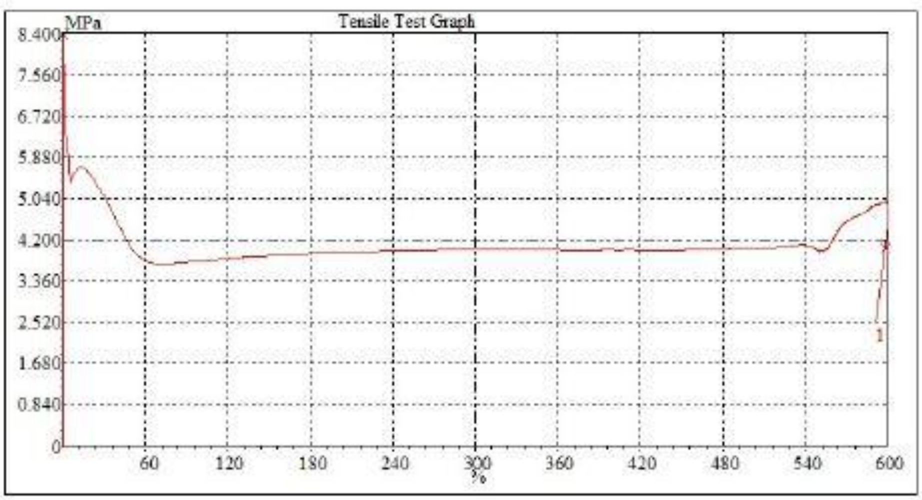
Tensile Test Report

Material :Composite Carbon Fibre
Test Method :ASTM D638

Test Speed : 20.000 mm/min

Test No.	Thickness mm	Width mm	Max. Load N	Elastic Modulus MPa	T.Strength MPa	Y.Load N	Y.Strength MPa	Elongation@Break %
1	9.500	15.00	1192	-	8.37	-	-	597.81
---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---
Average	9.500	15.00	1192	0	8.37	0.000	0.000	597.81
SD(N-1)	0.000	0.00	0	0	0.00	0.000	0.000	0.00



Tensile Test Sample 12k+6k

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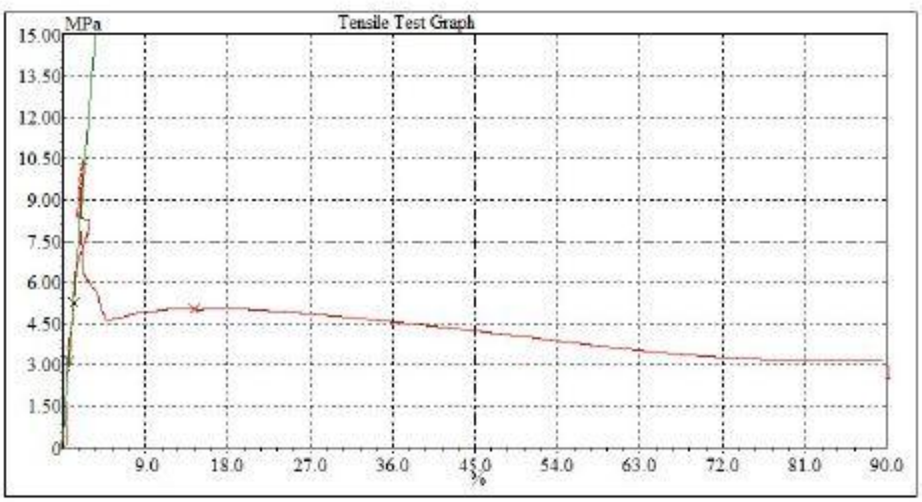
MECHANICAL ENGINEERING DEPARTMENT
BANDAR SERI ISKANDAR
31750, TRONOH
PERAK.

Tensile Test Report

Material :Composite Carbon Fibre
Test Method :ASTM D638

Test Speed : 20.000 mm/min

Test No.	Thickness mm	Width mm	Max. Load N	Elastic Modulus MPa	T.Strength MPa	Y.Load N	Y.Strength MPa	Elongation@Break %
1	9.000	15.00	1406	366	10.41	-	-	14.38
---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---
Average	9.000	15.00	1406	366	10.41	0.000	0.000	14.38
SD(N-1)	0.000	0.00	0	0	0.00	0.000	0.000	0.00



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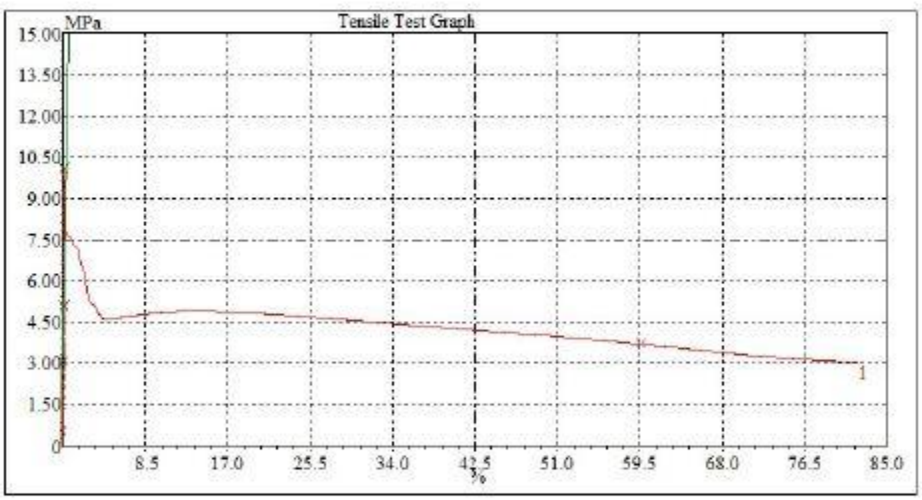
PERAK.

Tensile Test Report

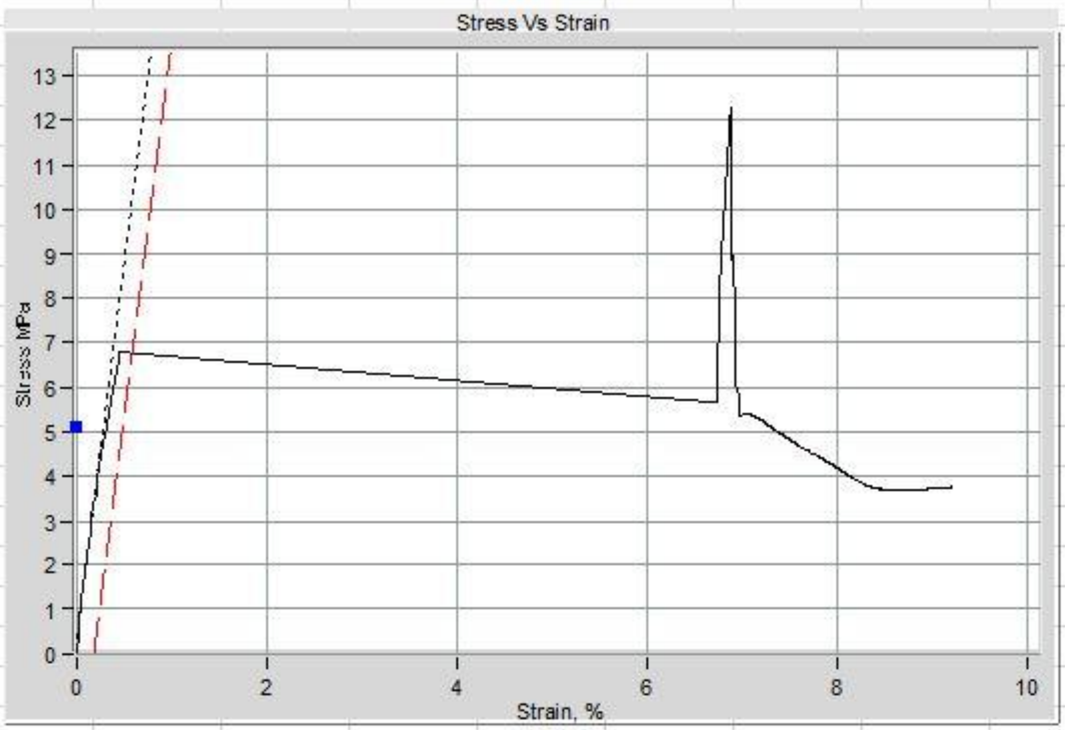
Material :Composite Carbon Fibre
Test Method :ASTM D638

Test Speed : 20.000 mm/min

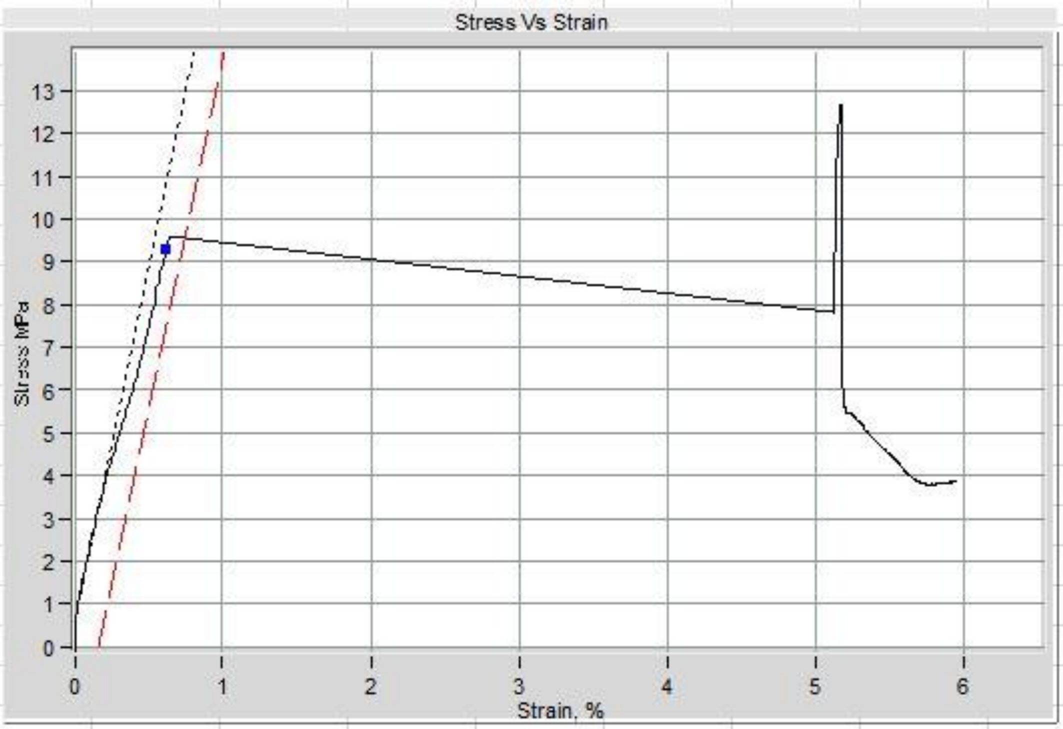
Test No.	Thickness mm	Width mm	Max. Load N	Elastic Modulus MPa	T.Strength MPa	Y.Load N	Y.Strength MPa	Elongation@Break %
1	9.000	15.00	1359	2048	10.07	-	-	59.53
---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---
Average	9.000	15.00	1359	2048	10.07	0.000	0.000	59.53
SD(N-1)	0.000	0.00	0	0	0.00	0.000	0.000	0.00



Tensile Test Sample 6k



Peak Stres	12.305	MPa		
Peak Load	1.846	kN		
0.2% Offs	5.658	MPa		
Yield Strai	6.739	%		
Yield Loac	0.849	kN		
Modulus:	1.689	GPa	244.908	ksi



Peak Stress:	12.656	MPa	
Peak Load:	1.898	kN	
0.2% Offset Yield Stress:	7.833	MPa	
Yield Strain:	5.126	%	
Yield Load:	1.175	kN	
Modulus:	1.642	GPa	238.107 ksi

Compression Test All Samples Summary